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PROGRAM TO DEVELOP HIGH STRENGTH ALUMINUM POWDER METALLURGY PRODUCTS

PHASE I - PROCESS OPTIMIZATION

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SYNOPSIS

Aluminum-based P/M hand forgings and extrusions in two Al-Zn-Mg-Cu alloys have been studied to evaluate the effects of powder processing variations on forging quality and properties and extrusion properties. High quality hand forgings with high strength and ductility have been produced directly from hot pressed aluminum powder compacts without an intermediate extrusion operation.

Among the MA58 forgings, 87 volume % of the forgings met or exceeded SNT Class "A" quality standards, while 71 volume % of the MA39 met or exceeded SNT Class "A" standards.

P/M MA58 and MA39 alloy forgings achieved strength, ductility and longitudinal toughness comparable to 7075-T6 hand forgings. These P/M forgings were resistant to stress corrosion cracking and exfoliation corrosion in accelerated tests of samples from 2" square hand forgings.

While neither cold compacting method nor green density affected forging properties, preheat time and temperature and hot coin pressure had significant effects on forging properties or quality. Increasing preheat time was detrimental in both MA58 and MA39, in the latter case due to Ostwald ripening of Co_2Al_9 constituent. Increasing preheat temperature promotes more thorough compact degassing. Raising the hot compacting pressure decreased cracking during forging and netted increased properties.

The processing conditions leading to maximized hand forging properties are:

- Cold press to at least 70% green density;
- Preheat 1 hour at 1,000 F in dry argon;
- Hot press at 90 ksi;
- Forge at a temperature appropriate for the specific alloy;
- Forge by any standard hand forging press technique with as much total reduction as possible.

For preparing extrusion billets, either uniaxial or isostatic cold compacting can be used in generating extrusions with comparable properties.

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PHASE I - P/M PROCESS OPTIMIZATION

INTRODUCTION

Of the commercial high-strength aluminum alloys currently available, alloy 7075 and variants of 7075 have the best combinations of strength, stress-corrosion cracking resistance, fracture toughness and ductility. Variations in desirable combinations of properties can be obtained, but generally at ultimate strengths of 75,000 psi or less.

An earlier Alcoa Research Laboratories (ARL) investigation for the U.S. Army[1,2,3] developed powder metallurgy alloys having combinations of high strength (>7075-T6) and resistance to stress-corrosion cracking which are unobtainable with conventional aluminum products. Further, that same investigation developed a P/M process for fabricating mill products (i.e. extrusions) which have higher ultrasonic quality than conventional mill products.

The emphasis in that investigation was on extrusions because that process had a higher chance of success in fabricating compacts than other fabricating processes, e.g. rolling, forging, and impacting. The plate, sheet, and impacts were made mostly from extruded stock. For large plate and forgings, it is necessary to eliminate the intermediate extrusion; for this reason, Phase I of this investigation was undertaken to optimize the processing conditions for producing forgings from compacts without an intermediate extrusion operation.

The results of Phase I will form the basis for the scale-up in size which is a part of Phase III.

The vehicles for Phase I are two high strength Al-Zn-Mg-Cu alloys, one with, and the other without, sizable additions of ancillary elements. One is MA39 which has demonstrated good combinations of strength and resistance to stress corrosion cracking in earlier work at Alcoa and in the earlier Army contract. The second alloy, MA58, is a powder metallurgy version of X7050, one of the most promising of the new alloys when fabricated from ingot. Before registration with the Aluminum Association, X7050 was designated MA15. MA58 differs from X7050 in that the former contains oxygen.

Variables included in this program are:

Alloy
Cold Compacting Method
Cold Compact (green) Density
Preheat Time
Preheat Temperature
Hot Compacting Pressure
Forging Temperature
Forging Procedure
Amount of Hot Reduction

Several small investigations were added to this phase to develop other processing information of interest for the concurrent Phase II investigation and for the planned Phase III scale-up. These investigations included:

1. Determine if cold compacting method affects extrusion properties.

2. Determine a technique for detecting melting in P/M materials (Reported in Appendix I).

3. Fabricate M16 Receiver forgings from Phase I. alloys (Reported in Appendix II).

OBJECTIVES

1) Determine the processing conditions for optimum forgeability and properties.

2) Determine the minimum cold compact density and minimum hot compacting pressure that will yield acceptable forgeability and properties.

PROCEDURE

I. Optimum Process for Forgings

Forgings were made by a process consisting of atomizing, cold compacting, preheating, hot pressing (or coining), hand forging, solution heat treating, quenching, and aging. The processing conditions are discussed in connection with the variables being evaluated.

A. Powder Preparation

The alloys shown in Table 1 were prepared by melting and alloying to net approximately 1,500 pounds of the desired alloy. Following a check of melt analysis and minor chemistry adjustments, each alloy was atomized to yield powders having the screen analyses shown in Table 2. After scalping through a No. 50 (U.S. Standard) screen, two 500 pound batches of each alloy powder were split and subsequently blended in 100 pound batches in a vee-blender for 30 minutes.

B. Cold Compacting

Using a 1,500 ton vertical press, the powders were cold compacted uniaxially in a steel die with butyl stearate

for a die wall lubricant (Figure 1). Cold compact densities of 70% and 80% of theoretical density were obtained by cold pressing the equivalent of 160 cubic inches of metal as powder (16.32 and 16.44 pounds for MA58 and MA39, respectively) into tapered volumes of 229 or 199.5 cubic inches, respectively. The resultant compacts were approximately 6" diameter x 8" or 7" long for 70% of 80% cold density, respectively. To supplement the information generated with uniaxial cold compacting, samples K1, K5, K7, K8, K9, and K10 listed in Table 3 plus other compacts listed in Table 4 were cold pressed by isostatic cold pressing using a wet bag process.

Isostatic compact green density was calculated from powder charge weights and compact dimensions as determined with calibers and a rule having 1/64" graduations. Uniaxial compact green densities were calculated from compact dimensions and powder charge weight.

Powder cold compacting pressure vs compact density for uniaxial and isostatic compacting of MA58 and MA39 alloys is summarized in Table 4. In Figure 2, uniaxial (mechanical compacting in a tapered die) compacting is compared to isostatic for the two alloys, for nominally 6" diameter compacts. Pressure attenuation from the ram surface through the compact and die wall friction in uniaxial pressing result in the less efficient use of applied pressure than with isostatic pressing.

The effect of natural aging time (after atomizing) on the pressure versus cold compact density relationships for MA58

and MA39 is shown in Figures 3 and 4, respectively. The shift in pressure versus density is probably the result of the powder becoming stronger and more resistant to deformation (by natural aging) with increased time after atomizing.

The effect of compact diameter on cold compact density for isostatic pressing is shown in Figures 5 and 6, including information on 11" diameter cold compacts[7]. Increasing compact diameter appears to lower green density slightly for compacts pressed at the same pressure. However, the differences in compact density relative to compact size are small and might be overshadowed by the effect of powder natural aging (e.g. Figures 3 and 4).

C. Preheating

The compacts were preheated in a sealed muffle furnace, the muffle having a volume of 38 cu. ft. The atmosphere was argon flowing at 300 CFH from a tank of liquid argon. Preheat times were nominally 1, 5, and 20 hours, and temperatures were 900, 950, and 1,000 F.

To determine the effect of repeated door openings on the preheating atmosphere, analyses of furnace exit gas shown in Table 5 were determined. After 4.5 hours at 950 F without door openings with 6 compacts in the furnace, oxygen was at a low level and N_2 was the principle contaminant in the argon atmosphere. Opening the furnace door diluted the argon to approximately 50%, with air (of 80% N_2, 20% O_2) making up the balance of the furnace gas. After closing the door, the nitrogen and

oxygen were diluted by argon, but the proportion of N_2 to O_2 increased. This suggests some oxygen consumption in the furnace, by the powder compacts or the furnace muffle (stainless steel). No evidence of appreciable compact oxidation due to door openings has been observed (see section IB 3., Results and Discussion).

D. Hot Compacting

Immediately upon completion of preheating, the compacts were hot pressed in a 700 F die (Figure 7) at 30, 60, and 90 ksi, the pressure being held for one minute. There were ejected from the die and air cooled.

E. Scalping

The compacts were scalped to cylinders 6.1" diameter x 4.8" long by removing approximately 0.1-0.2" from the radius and 0.2" from the length.

Densities of selected scalped compacts were measured by the weight in air - weight in water method. No billet density differences were observed for variations in hot compact pressure, preheat temperature or green density (see Table 6 and 7). As little as 30 ksi hot compact pressure after a billet preheat at 900 F was sufficient to raise the billet to 100% of theoretical density.

F. Forging

The P/M billets were reheated and forged on a 3,000 ton hydraulic press at Alcoa's Cleveland Works. Heated (360-700 F)

cogging dies were used with a 3" edge radius and no lubricant (dies occasionally salted to control metal sticking). The forging procedures used are listed in Tables 3, 8, 9, and 10, and illustrated in Figures 8 to 11. The forgings listed in Table 8 explored metal working temperatures from 540 F to 750 F. From the visual quality of the resultant 2" x 2" x 30" forgings, metal working temperatures of 600 and 700 F were chosen for MA58 and MA39, respectively. These metal temperatures were used in all subsequent forging. Various working methods and amounts of reduction were used on the forgings listed in Table 9 to determine the effect of these parameters on the properties of P/M forgings. The forging methods used on the specific "B" forgings as well as the final forging sizes are listed in Table 9.

The remaining forgings in Tables 3 and 10 were worked by drawing (Figure 8) in the billet pressing direction to 2" x 2" x 30" long.

G. Forging Inspection

In preparation for the visual inspection of the forgings, each was subjected to a sodium hydroxide-nitric acid etch sequence to aid crack detection. The forgings were then visually inspected for number and severity of obvious end, corner and face cracks.

Ultrasonic inspection was conducted to determine the extent of end and face cracking and to rate the quality of the uncracked

portion of each forging relative to SNT Class "A" Standards. In the uncracked portion of each forging, the inspection noted ultrasonic noise and the location and size of isolated discontinuities. The ultrasonic test was conducted using a 10 MHz, 3/4" diameter lithium sulfate search unit and standardizing for a 2.0" trace-to-peak indication from the 3-0075 (No. 3) reference block (3/64" diameter flat bottomed hole at a metal distance of 3/4"). A Sperry UM721 Reflectoscope was used for the test. Each hand forging was inspected by sending the ultrasonic waves through two orthogonal directions. The volume of metal meeting SNT Class "A" Standards was computed and recorded as "percent metal recovery."

H. Heat Treatment, Sampling

The forgings listed in Tables 3, 8, and 10 were heat treated as 2-inch square hand forgings. The MA58 and MA39 alloy forgings were solution heat treated at 890 F and 920 F, respectively, for 2 hours and cold water quenched. These temperatures were selected from other investigations on X7050[4] and MA39 (Appendix I). After 7 days natural aging, the forgings were artificially aged by heating at 100 F/hour to 250 F, then holding 24 hours at 250 F. The MA58 and MA39 forgings were further aged 8 and 16 hours, respectively, at 330 F by heating from room temperature to 330 F at 100 F/hour, holding for the times shown. Tensile and notched tensile specimens were taken as shown in Figure 12.

The forgings listed in Table 9 were sampled initially by cutting one-inch thick slices from each 3.25-inch square, 2.0-inch square, or 1.25-inch square forging, as shown in Figures 13, 14 and 15. These one-inch thick slices of MA58 and MA39 alloy forgings were solution heat treated at 890 F and 920 F, respectively, held 2 hours and cold water quenched. After 6-7 days natural age, these slices were artificially aged by heating at 100 F/hour to 250 F, holding 24 hours at 250 F. The MA58 and MA39 samples were further aged by heating at 100 F/hour from room temperature to 330 F and held 8 and 16 hours, respectively, at 330 F. Tensile and notched tensile specimens were taken from the one-inch thick slices as shown in Figures 13, 14 and 15.

Exfoliation and transverse stress corrosion samples were taken at locations shown in Figure 16 for the forgings listed in Table 11. These forgings represent the optimum processing conditions from considerations of forging quality, tensile and notched tensile properties. The exfoliation test on panels shown in Figure 16 was a Modified ASTM Acetic Acid-Salt Intermittent Spray at 120 F[5]. The transverse tensile bars for stress corrosion cracking test were stressed at 42 or 25 ksi and exposed to a 3-1/2% NaCl solution by alternate immersion for 84 days[6].

The response of MA58 and MA39 to second step aging was determined on the forgings listed in Table 12 by re-heat treating 2" square x 8" long forging sections, cold water

quenching, natural aging 6 days, and artificial aging 24 hours at 250 F plus 2, 4, or 8 hours at 330 F (as shown in Table 12).

The oxygen content of selected 2" square forgings that represent various preheat conditions was determined by neutron activation analysis. These forgings are listed in Table 13.

I. Data Analysis

Initial assessment of the effect of processing variables on mechanical properties was accomplished by averaging properties of comparable forgings under each value of a primary processing variable. An example of this comparison is shown for the effect of green density on properties (Table 1, Appendix III). These data compilations are shown in Appendix III for comparisons of the effects of green density, preheat temperature, preheat time, and hot compacting pressure on tensile properties of P/M hand forgings.

The statistical data analysis for primary variable comparisons consisted of determining averages and Σ (deviations)^2 for each primary variable and testing for significance of differences between primary variables with a "Students' t test." A probability of 95+% for a single-tailed test was considered a significant difference if the samples were considered representative. These analyses are shown in Tables 1 to 18, Appendix III.

An analysis of variance to determine the possible interactions among processing variables was conducted on Tables 41, 42, 44, 45, 47, 48, 50, 51, 53, 54, 56, and 57 using an "F"

test to determine the significance of trends and possible interactions.. A 95+% probability was considered to be a significant variance by this analysis.

II. Effect of Cold Compacting Method on Properties of Extrusions

A. Extrusion Preparation

The alloys shown in Table 14 were prepared by melting and alloying to net approximately 150 pounds of MA39 and 300 pounds of MA58. After a check analysis and minor chemistry adjustments, the MA39 was atomized to yield fine powder having the screen analysis shown in Table 15. The MA58 was atomized using two conditions to yield fine and coarse powders, as shown in Table 15. The chemical analyses of the MA58 extrusions in Table 14 show that two sizes of powder can be produced from the same melt with only minor variations in alloy chemistry.

After scalping through a No. 100 (U.S. Standard) screen (MA39 and MA58 fine powder) or No. 25 screen (MA58 coarse powder), the powder was compacted to 75% of theoretical density by uniaxial and isostatic compacting methods. The resultant compacts were approximately 6" diameter x 8" long. The compacts were preheated in dry flowing argon for 4.5 to 5.5 hours at 950 F. Immediately following preheat, the compacts were hot pressed to 100% density in a heated (700 F) 6-3/8" diameter extrusion cylinder by pressing against a blind die at 90 ksi pressure and then extruded (direct) into the section illustrated in Figure 17.

B. Heat Treatment, Sampling

Sections of extrusions were heat treated in a dry air atmosphere, for 2 hours at 890 F (MA58) or 920 F (MA39) and quenched in cold water (200 F/sec. in the temperature range 750-550 F). After 7 days natural aging the extrusions were artificially aged 24 hours at 250 F plus 8 hours at 330 F (MA58) or 16 hours at 330 F (MA39). Heat-up rates of 100 F/hour were used for all aging treatments.

Longitudinal and transverse tensile and notched tensile specimens for comparison of uniaxial and isostatic compacting methods were machined from the extrusion as shown in the sampling layout in Figure 17.

RESULTS AND DISCUSSION

I. Optimum Process for Forgings

A. General Comments on Quality and Properties

The initial assessment of forging quality was made on the basis of visually detected cracks on the ends, corners and faces of the hand forgings to allow selection of forging temperature and forging procedure for subsequent fabrication. Since ultrasonic inspection and mechanical properties provide a more thorough judgment of metal quality, the quality rating discussion that follows is based principally on the results of ultrasonic inspection and mechanical properties of forgings. It should be noted that the results of the visual inspections

either follow the trends indicated by ultrasonic quality and properties, or show no trend as a function of a processing variable.

The volumes of the P/M billets and the volume of the unsound portion of each forging are presented in Tables 16 and 17. The percent sound material in each forging is summarized in Tables 17 and 18 for all forgings prepared.

The longitudinal and transverse tensile and notched tensile properties of P/M MA58 and MA39 forgings are listed in Tables 19 and 20, respectively. The processing conditions that describe each forging are shown in Tables 3, 8, 9, and 10.

A number of general observations can be made in examining the forging quality data to be discussed in following sections. Metal recovery and ultrasonic quality were quite high.

Averaging over all the P/M hand forgings, 82% of the forgings (by volume) passed SNT Class A quality standards. This compares with 73% over all metal recovery for 2" diameter extrusions prepared from P/M billets in Phase II of this program.

The portions of the forgings that showed evidence of cracking were generally associated with ends of the compacts, particularly the end of the compact opposite the ram that experienced little metal movement in hot pressing. In addition to scalping the billet more severely, it might be possible to eliminate this problem by artificially moving the metal during the hot pressing, as one might by pressing against a shaped rather than a flat blind die.

After eliminating the obvious cracked portions of each forging, 98% by number (93 out of 95) of the forgings met or exceeded the ultrasonic inspection standards for SNT Class "A" metal quality.

The average ultrasonic noise level noted in the uncracked portions of all the P/M forgings was at a low level relative to the level commonly found in forgings from commercial ingot. The noise ranged from 5 to 12% of the response of a No. 3 reference standard. Because of the low level of noise observed, values for each forging are not reported here. The generally high quality level makes the effects of processing variables on forging quality somewhat unclear, as may be seen in the following discussion.

B. Effects of Process Variables on Quality and Properties

1. Effect of Alloy on Forging Quality and Properties

By nearly every measure of forging quality, MA58 alloy forgings were superior to forgings of MA39 alloy. Summing over all powder processing and metal forging conditions, the metal recovery for MA58 was 87% (volume of forging meeting SNT Class "A" quality standards) compared to 71% metal recovery for MA39 alloy (Table 21).

The only quality factor that favored MA39 alloy was in the number of isolated discontinuities detected ultrasonically (Table 21). Over all the powder processing and forging conditions

examined, MA58 alloy averaged 2.2 discontinuities per forging, while MA39 averaged 0.5 discontinuities per forging. It is important to note that the isolated defects found in forgings of both alloys are small and spaced so the uncracked forging exceeds SNT Class A quality standards.

The average properties of all MA58 and all MA39 forgings are summarized in Table 22.

The average tensile strengths are nearly identical for both alloys in both longitudinal and transverse directions. However, the MA58 alloy forgings have higher yield strength, elongation and notched tensile strength:yield strength ratio (NTS/YS) in both test directions.

2. Effect of Cold Compacting Variations on Forging Quality and Properties

a. Green Density

Summing over both alloys and all processing conditions (Table 23), a cold compact density of 70% is slightly favored over 80% for metal recovery. This advantage is not statistically significant by a t-test.

The forgings from 70% cold density compacts had twice as many isolated discontinuities as forgings from 80% density cold compacts, while still meeting SNT Class "A" quality standards in the uncracked center portion of each forging (Table 23).

The effect of cold compact density on properties of forgings is summarized in Table 24. From the summary table,

it can be seen that only a few scattered significant differences in properties exist. Seventy percent green density was favored slightly for MA58 transverse properties, although only the tensile strength and yield strength differences are statistically significant. Eighty percent green density gave slightly higher longitudinal properties in MA58, but only the elongation difference shown statistically favors 80% green density.

For MA39 alloy forgings, the only property differences shown in Table 24 are in transverse elongation and notched tensile strength. The differences between 70 and 80% are not statistically significant.

Overall, it is seen that compact green density has no practical effect on the properties of P/M hand forgings.

b. Cold Compact Method

The results of inspections of forgings for determining the effect of cold compacting method on forging quality are presented in Table 25.

There is no significant difference in metal recovery between forgings prepared from isostatic and uniaxial cold compacts; both methods yield 78% over-all metal recovery for the processing conditions represented.

Forgings from uniaxial cold compacts had slightly more isolated discontinuities than forgings from isostatic cold compacts.

The effect of cold compacting method on properties of forgings is shown in Table 26.

For MA58 forgings, notched tensile strength:yield strength ratio in both test directions favors isostatic compacting, while transverse elongation favors uniaxial compacting. The transverse NTS/YS and elongation are the only MA58 properties with statistically significant property differences.

For MA39 forgings, the longitudinal NTS/YS favors uniaxial compacting, while the transverse NTS/YS favors isostatic pressing. However, none of the property differences noted statistically favor one compacting method over the other.

Overall, isostatic cold compacting is comparable to uniaxial cold compacting.

3. Effect of Preheat Variations on Forging Quality and Properties

a. Preheat Temperature

The effect of preheat temperature on forging quality is presented in Table 27. The trend shown indicates a general improvement in metal recovery with increasing preheat temperature.

The intermediate preheat temperature results in forgings with the least number of discontinuities. This might be related to melting these alloys above 950 F to generate discontinuities without resulting in forging cracks.

The effect of preheat temperature on properties of forgings is summarized in Table 28.

For MA58 forgings, 1000 F preheat temperature gives the highest longitudinal and transverse elongation and notched tensile strength at comparable tensile and yield strengths for the 900-1000 F preheat temperature range. This advantage for 1000 F preheat temperature is statistically significant for MA58.

For MA39 forgings, the 1000 F preheat was the highest strengths and elongations (both directions) and the highest transverse notched tensile strength. However, only the longitudinal tensile and yield strength (1000 vs. 900 F) and the transverse notched tensile strength (900 or 1000 vs. 950 F) differences are statistically significant.

Overall, the use of 1000 F preheat appears to significantly improve forging properties.

b. Preheat Time

The role of preheat time in forging quality is presented in Table 29. Summing over all the variables, 20 hour preheat does net slightly better average metal recovery.

The 20 hour preheat netted forgings with 1/3 the number of isolated discontinuities of either the 1 or 5 hour preheats.

The effect of preheat time on properties of forgings is summarized in Table 30.

For MA58 forgings, one-hour preheat yields the highest transverse elongation and tensile, yield and notched tensile strengths in all directions. The one-hour preheat is statisti-

cally favored for notched tensile strength in both directions and for transverse tensile strength.

The one-hour preheat is statistically favored for MA39 notched tensile strength in both directions. The other properties determined show the one and five hour preheats to be generally comparable.

Overall, the one-hour preheat is favored over longer preheats times for optimum toughness.

c. Interaction of Preheat Time and Temperature

Neutron activation oxygen analyses were run on compacts preheated at 900 to 1000 F to determine if the decreasing toughness with increased preheat time could be attributed to increased oxygen, present as MgO or $MgAl_2O_4$ (spinel). The results of oxygen determinations are presented in Table 31 for forgings made from MA39 and MA58 compacts preheated various times. Within the precision of the measurement, no increase in oxygen occurs between the 1 and 20 hour preheat.

The coarsening of the Co_2Al_9 phase during compact preheat is shown in Figure 18 for 1 and 20 hour preheats at 1000 F and by the measurements presented in Table 32. The average particle diameter doubled during a 20 hour preheat at 900 F and increased by 2.3 times during 20 hour at 1000 F. The diffusion rates necessary for this Ostwald ripening strongly suggest predominantly high diffusivity path diffusion (e.g. grain and subgrain boundaries).

The effects of average particle diameter and interparticle spacing on longitudinal and transverse NTS/YS are shown in Figures 19 and 20, respectively. The NTS/YS in both directions decreases with increasing I-P spacing or average particle diameter. Clearly, minimizing preheat time for alloys with appreciable Co (and perhaps Fe and Ni) is desirable to maintain optimum toughness.

Surprisingly, the 1000 F preheat generally results in higher toughness than 900 F preheat (see Table 28) in spite of coarser Co_2Al_9 after the higher temperature preheat (see Table 32). Apparently the higher temperature more thoroughly degasses the green compact, resulting in a hot pressed compact with less total gas content. The net effect of higher preheat temperature, then, is better forging toughness even in the presence of Ostwald ripening of constituent.

4. Effect of Hot Compacting Pressure on Forging Quality and Properties

The effect of hot compacting pressure on the quality of P/M forgings is presented in Table 33. The general trend noted is improving metal recovery with increasing hot compact pressure. The greatest percentage improvement in metal recovery is had in going from 30 ksi to 60 ksi hot compact pressure, especially for alloy MA39.

Summing over a variety of processing conditions, the difference in metal recovery between 30 ksi and 60 ksi hot compact pressure is statistically significant, while the difference between 60 ksi and 90 ksi is not significant.

The 60 ksi hot compacting pressure does result in more discontinuities than either 30 or 90 ksi. Apparently the material lost to cracks with 30 ksi hot compacting pressure is uncracked at 60 ksi, but contains numerous isolated discontinuities. At 90 ksi, this material is uncracked and relatively free of discontinuities. In spite of the number of discontinuities noted at 60 ksi, these forgings still all pass SNT Class "A" Standards.

The effect of hot compacting pressure on properties of forgings is summarized in Table 34.

For MA58 forgings, 90 ksi hot compacting pressure yields the highest notched tensile strength and elongation. Only the difference in transverse elongation between 90 ksi and 30 ksi is statistically significant.

For MA39 forgings, 90 ksi hot compacting pressure gave the highest transverse notched tensile strength and elongation, while 60 ksi was best for longitudinal elongation and notched tensile strength. None of the differences in elongation or notched tensile strength noted from Table 34 are statistically significant. The forgings hot pressed at 60 ksi did have statistically significant higher transverse strength than was the case for 90 ksi. None of the other property differences shown are significant.

The effect of hot compacting pressure on NTS/YS and percent metal recovery (see Table 34) is shown in Figure 21. Ninety ksi hot compacting pressure yields the highest NTS/YS in forgings.

The use of 90 ksi hot compacting pressure is presently preferred to achieve maximum properties from forgeable P/M compacts. This variable must be evaluated further in Phase III with the expectation of finding that 60 ksi may be adequate in practice.

5. Effect of Forging Technique Variations on Forging Quality and Properties

a. Metal Temperature

For MA58 alloy, visual quality rating (Table 35) shows minimized edge and face cracking for 600 F forging temperature. A temperature range of 500-600 F for metal working was selected for all subsequent forging of MA58. For MA39, similar visual quality rating (Table 35) shows minimized face and edge cracking for 700 F forging temperature. A temperature range of 600-700 F for metal working was selected for all subsequent forging of MA39.

The effect of forging temperature on metal quality is noted in Table 36. In terms of metal recovery, the optimum metal working temperature is a function of alloy content. The MA58 alloy forgings gave the best metal recovery when worked from 550 to 600 F. In practice, metal temperatures from 500-600 F were used in working MA58.

The MA39 forgings gave the best metal recovery when worked at 650 to 700 F metal temperature. In practice, a metal temperature range of 600 to 700 F was used for forging MA39 alloy.

The effect of forging temperature on properties of P/M hand forgings is shown in Tables 37 and 38.

For MA58 alloy, the temperature range from 550 to 750 F yields desirable longitudinal properties, with 600 F and 700 F having particularly good combinations of elongation and NTS/YS. In the transverse direction, the 550-700 F temperature range (excepting 650 F) has the best NTS/YS, while 650 F has the best elongation. Considering properties in both directions, the temperature range from 600-700 F appears optimum for MA58 alloy.

For MA39 forgings, 700 F forging temperature gives optimum transverse elongation and NTS/YS, while 750 F has a longitudinal elongation advantage. Since forging recovery drops off drastically at 750 F (Table 36) forging at 700 F for MA39 appears best.

b. Forging Procedure

The effect of forging procedures and amounts of reduction on forging visual quality are shown in Table 39. Using minimized face and edge cracking as the principle quality criterion, a "draw" operation (Figure 8) for both MA58 and MA39 alloys gave the best forging quality. For MA58 alloy, an "A upset and draw" operation (Figure 9) gave nearly the same quality as a simple draw operation.

The metal quality ratings as a function of type and amount of working are presented in Table 40.

For both MA58 and MA39, increasing amounts of work in going from a 3.25" square bar to a 1.25" square bar results in improved average recovery. However, for MA58, the differences in recovery are not statistically significant. For MA39, the metal recovery improvement with increased work is significant.

The different forging operations (i.e. draw, A upset and draw, etc.) netted slightly different average metal recoveries for both alloys, but the differences in recovery are not statistically significant.

"A" upset and draw forging, while netting the best metal recovery, gave forgings with more isolated discontinuities for MA58. For MA39 alloy, A or A-B upset and draw forgings had the most discontinuities.

The amount of end cracking was least severe for the A or A-B upset and draw operations for both MA58 and MA39 forging operations, as shown in Figures 22 and 23, respectively. Thus the severity of end cracking is seen to run contrary to the number of discontinuities.

The effects of deformation procedure on properties of MA58 and MA39 forgings are shown in Tables 41 and 42, respectively. Only minor differences in elongation and NTS/YS will be noted in examining the properties as affected by deformation method. None of these differences are statistically significant for either alloy. Any of the deformation methods used will yield nearly equal properties.

The effects of amount of deformation on properties of MA58 and MA39 forgings are shown in Tables 41 and 42, respectively. For both alloys, tensile and yield strength increase with increasing amounts of extension in working. This increase in strength is statistically significant for MA58 longitudinal YS and transverse TS and YS, and for MA39 longitudinal TS.

Of greater significance is the good longitudinal elongation and NTS/YS with as low an extension ratio (L = forging length/ billet length) of 2.8, as shown in the properties of the 3.25-inch square forgings for both MA58 and MA39. Either the hot pressed compact has favorable properties, or only small amounts of reduction are required to generate good properties. This small amount of reduction was sufficient to generate considerable anisotropy, notably in NTS/YS.

Small improvements in longitudinal NTS/YS are gained with increased reduction for MA58 alloy, but elongation in all directions and transverse NTS/YS are not significantly affected by increased reduction. Increased reduction in MA39 forgings does not appreciably affect elongation or NTS/YS in either test direction.

Overall, since increased reduction does improve strength with possible NTS/YS improvements, optimum forging practices should allow as much reduction in section as possible. For hand forgings, this would mean starting with the largest possible billet size.

6. Effect of Process Parameter Interactions on Forging Quality and Properties

a. Interactions of Alloy, Green Density, Preheat Time and Temperature on Forging Quality and Forging Properties

The above interactions are shown quantitatively in Table 43 and qualitatively in Figure 24. For MA58 alloy forgings, there are no appreciable interactions among the above parameters in metal recovery. Eighty percent green density does result in more severe forging end cracking (Figure 24) but fewer ultrasonic discontinuities.

For MA39 alloy, 1 hour preheat with 70% green density gave metal recovery equal to 20 hour preheat for 80% green density, regardless of preheat temperature. Eighty percent green density gave forgings with fewer discontinuities. None of these process interactions had any effect on the severity of end cracking for MA39, as seen in Figure 24.

The effect of the above interactions considered in Tables 44 and 45 shows no property vs. process parameter trends not already noted in the discussion of primary variables.

b. Interactions of Alloy, Green Density, and Hot Compacting Pressure

The above interactions on forging quality are the subject of Table 46. For MA 58 alloy forgings, no interactions resulted in quality trends contrary to those seen earlier in the single parameter comparisons.

For MA39 alloy, an interaction between hot compact pressure and green density results in the metal recovery reaching a peak at 60 ksi for 80% green density.

The effects of the above interactions on forging properties are considered in Tables 47 and 48. The significance of alloy on yield strength and elongation noted previously is seen here, with MA58 having higher Y.S. and elongation than MA39 for the longitudinal direction. The yield strength difference is largely the result of the aging practice difference, with the MA39 having a 16-hour second step age vs. MA58 having an 8-hour second step age. It appears that there is no important interaction of green density and hot coin pressure.

c. Interaction of Cold Compact Method, Hot Compact Pressure and Alloy on Forging Quality and Properties

No trends in metal quality contrary to the single parameter comparisons were observed due to the above interactions (see Table 49).

The effect of the above interactions on mechanical properties are considered in Tables 50 and 51. The following interactions were observed:

(1) Longitudinal tensile strength: MA58 favors uniaxial compacting; MA39 favors isostatic compacting.

(2) Longitudinal NTS/YS: MA58 favors isostatic compacting; MA39 favors uniaxial compacting.

Since the sample size involved in these interactions is small, it is possible that the small difference noted may be due to random property variations. Since the differences between properties is small, the differences may not be practically significant.

d. Interaction of Preheat Time and Temperature on MA58 Forging Quality and Properties

No trends contrary to the single parameter comparisons were observed due to the above interactions (see Table 52).

The effect of the above interactions on mechanical properties are considered in Tables 53 and 54. The trends in properties vs. process parameters are in agreement with previous observations noted in the discussion of primary process variables, excepting the unusually high transverse NTS/YS for the 1 hour at 900 F preheat. This value may be due to extreme experimental scatter.

e. Interaction of Preheat Temperature, Hot Compact Pressure and Alloy on Forging Properties

No trends contrary to the single parameter comparisons were observed due to the above interactions (see Table 55).

The effect of the above interactions on mechanical properties are considered in Tables 56 and 57. The only significant interaction is one observed in longitudinal NTS/YS. MA58 forgings preheated at 1000 F have optimum NTS/YS, while MA39 forgings slightly favor 950 F in the longitudinal direction and strongly favor 1000 F in the transverse direction. Since the sample size involved in this interaction is small, these interactions will be studied further in Phase III.

7. Effect of Processing Variations on Exfoliation Resistance

The 2" square forgings listed in Table 11 were exposed to two weeks in the MASTMAASIS accelerated exfoliation test[5].

No evidence of exfoliation was observed in the MA58 forgings, with only pitting type attack observed, as shown in Figures 25 and 26. Sample location in the forging had no apparent effect on depth of corrosion. However, higher green density or higher hot compacting pressure both result in increased maximum pitting depth of attack (see Tables 58 and 59) for alloy MA58.

While only pitting attack was visually observed in the MA39 forgings (somewhat more pronounced than MA58), there was evidence of slight undermining pitting in the MA39 forgings. Further, the MA39 forgings showed increased pitting depth of attack with increased preheat time as seen in Tables 58 and 59, and a lesser number of pitting locations observed in Figure 27 for the five hour preheats. This may be the result of Ostwald ripening of Co_2Al_9 in MA39 (shown in Figure 18), leading to fewer and further spaced locations for preferential corrosion. Lower hot compacting pressure decreases the maximum depth of pitting attack (Table 59) and increases the number of pitting locations (Figure 28).

8. Effect of Processing Variations on Stress Corrosion Cracking Resistance

The forgings listed in Table 11 were subjected to stress corrosion cracking tests. All specimens survived 84 days in A.I. test with no confirmed stress corrosion cracking

failures. The Ostwald ripening of Co_2Al_9 observed in MA39 apparently had no effect on the stress-corrosion cracking performance of MA39.

Since these MA58 and MA39 forgings have mechanical properties comparable to 7075-T6 forgings with immunity to exfoliation and stress corrosion cracking, either of these alloys would represent an improvement over 7075-T6 for hand forgings.

9. Second Step Aging Response of P/M MA58 and MA39 Forgings

The effect of second step aging time at 330 F on tensile properties of MA58 is shown in Table 60 and Figure 29. The second step age used for the bulk of the testing of MA58 forgings, 8 hours at 330 F, is about 4 ksi below the maximum longitudinal yield strength for these MA58 forgings.

The effect of second step aging time at 330 F on tensile properties of MA39 is shown in Table 61 and Figure 30. The temper used for the bulk of the testing of MA39 forgings, with a second step age of 16 hours at 330 F, is more than 15 ksi below the maximum longitudinal yield strength capability of MA39 forgings.

II. Effect of Cold Compacting Method o Properties of MA58 and MA39 Extrusions

For MA58 extrusions from both fine (83% -325 mesh) and coarse (29% -325 mesh) powder sizes, the longitudinal elongation and notched tensile strength to yield strength ratio favor

isostatic compacting (Table 62). The elongation for the fine powder size in the transverse direction favors uniaxial compacting, as does the transverse NTS/YS for the coarse powder size. When the data for the two MA58 powder sizes are grouped together, only the difference in longitudinal NTS/YS is statistically significant by a t-test (Table 63).

For MA39 extrusions, elongation and NTS/YS in both test directions favor uniaxial compacting. The differences are not statistically significant by a t-test (Table 62).

Overall, isostatic cold compacting is comparable to uniaxial cold compacting. This is consistent with the results of the comparison of hand forgings made from isostatic and uniaxial compacts.

SUMMARY

1. High quality hand forgings can be made from compacts of atomized high strength Al-Zn-Mg-Cu alloys without an intermediate extrusion operation.

2. An Al-Zn-Mg-Cu alloy without ancillary insoluble elements (MA58) had better forgeability, ductility, and toughness than an alloy containing insoluble additions (MA39).

3. The general level of recovery was high for hand forgings with 87 volume % of MA58 and 71 volume % of MA39 meeting SNT Class "A" Standard.

4. The effect of increasing green density from 70 to 80% on quality and properties was not significant.

5. Increasing preheat temperature from 900 to 1000 F increased forging quality, ductility and fracture toughness.

6. Increasing preheat time from 1 to 20 hours increased forging quality but decreased fracture toughness.

7. Increasing hot compacting pressure from 30 ksi to 90 ksi increased forging quality, fracture toughness and transverse ductility.

8. Optimum forging temperature ranges from 550 to 700 F, depending on alloy.

9. While working procedure has no significant affect on forging quality or properties, increasing amounts of work improves forging quality and strength.

10. The following powder processing conditions are recommended to maximize forgeability, forging properties and quality:

a. Cold press to more than 70% green density.

b. Preheat for 1 hour at 1000 F in flowing dry argon.

c. Hot press at 90 ksi.

d. Scalp, taking heavy cuts at the compact ends.

e. Forge by any standard working procedure at a temperature suitable for the alloy, with as much total reduction as possible.

11. Minimum processing conditions that yield acceptable forging properties are:

a. Cold press to 70% green density.

b. Preheat 1 hour at 900 - 1000 F.

c. Hot press at 60 ksi.

d. Scalp.

e. Forge by any standard working procedure with as little an extension ratio (forging length/ billet length) as 2.8.

12. Isostatic cold compacting gives extrusions with properties comparable to extrusions from uniaxial cold compacts.

RECOMMENDATIONS FOR PHASE III

I. Phase III Tooling

The Phase III tools (scale up to 170 lb. compacts) have been designed to prepare compacts by the optimum process technique determined in Phase I shown as (10) in the summary above. These tools have the following capabilities:

a. Cold isostatic compacting cylinder - 30 ksi compacting pressure, to produce a 170 lb. compact, 8.1" diameter x 44" long, >74% of theoretical density based on Figure 5.

b. Hot compacting cylinder - 90 ksi compacting pressure, to yield a 170 lb. compact, 8.4 to 9.2" diameter (tapered) x 28" long.

II. Process Variables for Phase III

The following process variations are to be studied in Phase III to determine: (1) how scaling up in compact size affects process variations and properties of products; (2) if less than 90 ksi hot compacting pressure will yield acceptable forging quality and properties; and (3) if fracture toughness can be improved by variations in powder size, preheat conditions or forging variations.

A. Powder Size

B. Preheat Conditions

1. Atmosphere

a. Controlled Purity

b. Inert Gas

(1) Argon

(2) Nitrogen

?. Heating Rate

3. Temperature

C. Hot Compacting Pressure

D. Scalping

E. Forging Method (increased amounts of hot work)

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6. D. O. Sprowls and R. H. Brown, "What Every Engineer Should Know About Stress Corrosion of Aluminum," Metals Progress Vol. 81 (4), April, 1962, pg. 79-85 and (5) May, 1962, pg. 77-83.
7. Unpublished Data - Research Notebook 13230-14.

TABLE 1

PHASE I ALLOY COMPOSITIONS

S. No.	Alloy	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Zr	Co	Oxygen (1)
379614	MA58	.04	.06	2.15	.00	2.19	.00	.00	5.88	.00	.10		.3
379615	MA39	.04	.06	.66	.00	3.39	.00	.01	8.83	.00	.01	.67	.3

NOTE (1) Estimated from Table 31.

TABLE 2

PHASE I POWDER SCREEN ANALYSIS

Powder Sample No.	Pot No.	Date Atomized	Screen Analysis (Weight Percent) +16	-16+30	-30+50	-50+100	-100+200	-200+325	-325
379614BD1	1277	020770	.0	.0	.0	.6	5.0	10.2	84.2
379614 D2	1277	020770	.0	.0	.0	.6	7.0	12.4	80.0
379615 D1	1276	020670	.0	.0	.0	.4	4.6	9.8	85.2
379615 D2	1276	020670	.0	.0	.0	.4	4.2	9.6	85.8

NOTES: (1) Samples taken before splitting and blending of powders.

(2) U.S. Standard series screen.

TABLE 3

ISOSTATIC AND UNIAXIAL COLD COMPACTING

Cold Compacting Method	FORGING CODE NUMBERS					
	MA58			MA39		
	Hot Compacting Pressure					
	30 ksi	60 ksi	90 ksi	30 ksi	60 ksi	90 ksi
Uniaxial (1)	C1	D1	A13	C5	D5	A14
Isostatic (2)	K7	K8	K1	K9	K10	K5

NOTES: (1) All uniaxial compacts of 70% green density.

(2) All isostatic compacts of 72% green density.

(3) All compacts preheated 5 hours at 950 F, hot pressed as shown above, scalped, fabricated by "draw" forging to 2" square.

TABLE 4

POWDER COMPACTING DATA FOR HIGH STRENGTH Al-Zn-Mg-Cu ALLOYS

Alloy S-No.	Compacting Method	Nominal Compact Dia. (inches)	Natural Age Interval (days)	Compacting Pressure (ksi)	Compact Nos.	Compact Density lbs/cu.in.	Compact Density (% of Alloy Density)
379614 (1) (MA58)	Uniaxial (3)	6.0	2	25.5 (4)		0.072	70%
	"	6.0	2	47.4 (5)		0.082	80%
	"	6.0	24	28.6 (6)		0.072	70%
	"	6.0	24	54.8 (7)		0.082	80%
	Isostatic	7.0	26	38.2	L-9, L-10	0.082	80%
	"	6.0	28	10.0	L-7	0.064	63%
	"	6.0	28	15	L-5	0.070	69%
	"	6.0	28	20	K-1, K-2, K-3	0.074	72%
	"	6.0	28	30	L-8	0.080	78%
	"	6.0	28	38.2	L-11	0.083	81%
379615 (2) (MA39)	Uniaxial (3)	6.0	4	32.2 (8)		0.072	70%
	"	6.0	5	60.1 (9)		0.083	80%
	"	6.0	25	34.8 (10)		0.072	70%
	"	6.0	25	65.1 (11)		0.083	80%
	Isostatic	7.0	26	35.9	M-9	0.078	75%
	"	7.0	26	38.2	M-10	0.079	76%
	"	6.0	29	10	M-6	0.065	63%
	"	6.0	29	20	M-5	0.072	70%
	"	6.0	29	25	K-4, K-5, K-6	0.074	72%
	"	6.0	29	38.2	M-7	0.081	78%
398784 (13) (MA49)	Isostatic	11.0	7	60.0		0.089	86%

NOTES

(1) 5.9 Zn, 2.2 Mg, 2.1 Cu, 0.1 Zr.
(2) 8.9 Zn, 3.3 Mg, 0.7 Cu, 0.7 Co.
(3) Uniaxial compact density derived from pressing to volume equivalent to compact densities shown.
(4) Average of 15 compacts.
(5) Average of 21 compacts.
(6) Average of 7 compacts.
(7) Average of 2 compacts.
(8) Average of 12 compacts.
(9) Average of 21 compacts.
(10) Average of 6 compacts.
(11) Average of 2 compacts.
(12) Isostatic compact density derived from averaged compact length and diameter, and powder charge weight.
(13) 7.8Zn, 2.5Mg, 1.0Cu, 0.71Fe, 0.75Ni (Ref. 7).

TABLE 5

COMPOSITION OF FURNACE EXIT GAS DURING COMPACT PREHEAT

Exit Gas Sample (2)	Argon	N_2	O_2	H_2	CO_2	H_2O (3)	N_2/O_2
After 4.5 hrs. at 950 F (5)	97.8	1.26	0.18	0.52	0.03	0.20	7.0
1 min. after door closing (4)	46.5	42.7	10.1	0.41	0.11	0.18	4.2
4 min. after door closing (4)	71.3	22.8	5.09	0.56	0.06	0.18	4.5
10 min. after door closing (4)	91.0	7.11	1.15	0.50	0.02	0.19	6.2

NOTES:
(1) Analytical Chemistry J.O. 70-031114.
(2) S-No. 379944-1 to -4.
(3) Water values should not be considered quantitative due to adsorption.
(4) Compacts K1, K2, K3 had been removed at 6 min. intervals before this sampling run started. Compacts K4, K5, and K6 remained in the furnace.
(5) Isostatic compacts K1, 2, 3, 4, 5, and 6 in furnace.

TABLE 6

P/M BILLET DENSITY (lbs./cu.in.) AS AFFECTED BY HOT COMPACTING PRESSURE AND PREHEAT TEMPERATURE FOR MA58 AND MA39 (PROJECT E)[1]

Alloy	Preheat Temperature	Hot Compacting Pressure 30 ksi	60 ksi	89.9 ksi
379614 (MA58)	900	.1021	.1021	.1021
379614 (MA58)	950	.1021	.1022	.1021
379614 (MA58)	1000	.1021	.1022	.1021
379615 (MA39)	900	.1031	.1032	.1032
379615 (MA39)	950	.1031	.1032	.031
379615 (MA39)	1000	.1031	.1032	.1032

NOTES: 1 - Billet density determined on scalped billets by a weight in air versus weight in water method.

TABLE 7

P/M BILLET DENSITY AS AFFECTED BY HOT COMPACTING PRESSURE AND COLD COMPACT DENSITY FOR MA58 AND MA39 (PROJECT F)[1]

Alloy	Cold Density (% of Theoretical)	Hot Compacting Pressure 30 ksi	60 ksi	89.9 ksi
379614 (MA58)	70	.1021	.1022	.1022
379614 (MA58)	80	.1021	.1022	.1021
379615 (MA39)	70	.1031	.1033	.1033
379615 (MA39)	80	.1031	.1032	.1031

NOTES: 1 - Billet density determined on scalped billets by a weight in air versus weight in water method.

TABLE 8

FORGING TEMPERATURE

	FORGING CODE NUMBERS				
	Forging Temperature				
Alloy	550	600	650	700	750
MA58	A4	A3	A6	A2	A1
MA39	A12		A7	A9	A8

NOTE: All uniaxial compacts, cold pressed to 70% green density, preheated 5 hours at 950 F, hot pressed at 90 ksi.

TABLE 9

TYPE AND AMOUNT OF DEFORMATION

Deformation Method	FORGING CODE NUMBERS (1) Finished Size 3.25"x3.25"	2"x2"	1.25"x1.25" (Stepped from 2.0" square)
Draw Only	B7, B14 (1)	B4, B11	B17, B21
A Upset & Draw	B1, B8	B5, B12	B18, B22
A-B Upset & Draw	B2, B9	B6, B13	B19, B23
A-B-C Upset & Draw	B3, B10	B15, B16	B20, B24

NOTES: (1) First number = MA58 alloy forging, second number = MA39 alloy forging.

(2) All uniaxial compacts, cold pressed to 80% green density, preheated 5 hours at 950 F, hot pressed at 90 ksi, forged as shown.

TABLE 10

GREEN DENSITY, PREHEAT TIME AND TEMPERATURE, AND HOT COMPACTING PRESSURE

FORGING CODE NUMBERS

Nominal (a)	Green Density	Preheat Temp.	30 ksi	60 ksi	90 ksi		
Hot Compact Pressure → Preheat Hours →			5	5	1	5	20
MA58 (379614)	70%	900			E1 (0.8)	J1 (4.8)	H1 (19.5)
		950	C1 (4.2)	D1 (4.2)	E2 (1.0)	A13 (4.25)	H2 (20.0)
		1000			E3 (0.8)	J2 (4.2)	H3 (19.7)
	80%	900	C2 (4.2)	D2 (4.5)	E4 (1.0)	J3 (5.0)	H4 (19.5)
		950	C3 (5.0)	D3 (5.2)		B25 (4.6)	
		1000	C4 (4.8)	D4 (5.0)	E5 (1.0)	J4 (4.5)	H5 (19.9)
MA39 (379615)	70%	900			E6 (1.0)		H6 (19.7)
		950	C5 (4.5)	D5 (4.5)		A14 (4.75)	
		1000			E7 (1.3)		H7 (20.0)
	80%	900	C6 (4.5)	D6 (4.8)	E8 (1.3)	J5 (5.0)	H8 (20.0)
		950	C7 (4.8)	D7 (5.0)		B26 (4.6)	
		1000	C8 (5.0)	D8 (5.2)	E9 (1.5)	J6 (4.5)	H9 (20.2)

(a) Actual preheat time in parentheses.
(b) All pieces shown fabricated by "Draw" forging to 2" square.

TABLE 11

FABRICATING CONDITIONS OF FORGINGS (1) TESTED FOR SCC AND EXFOLIATION RESISTANCE

Sample No.	Green Density (% of Theoretical)	Preheat Time (Hrs. at 1000 F)	Hot Coin Pressure (ksi)
MA58 Alloy			
379614 E3	70	1	90
E5	80	1	90
J2	70	5	90
J4	80	5	90
D4	80	5	60
MA39 Alloy			
379615 E7	70	1	90
E9	80	1	90
J6	80	5	90
D8	80	5	60

NOTE: (1) All "raw" forged to 2" square bar.

TABLE 12

FABRICATING CONDITIONS OF FORGINGS[1] REHEAT TREATED FOR STUDY OF RESPONSE TO SECOND STEP AGING

Sample No.	Green Density (% of Theoretical)	Preheat Time (Hrs. at 1000 F)	Hot Compact Pressure (ksi)	Second Step Age Times[2] (Hrs. at 330 F)
MA58 Alloy				
379614 E3, E10	70	1	90	2,4
379614 E5, E11	80	1	90	2,4
379614 J2, J7	70	5	90	2,4
379614 J4	80	5	90	2
379614 D4	80	5	60	2
MA39 Alloy				
379615 E7, E12	70	1	90	2,8
379615 E9, E13	80	1	90	2,8
379615 J6	80	5	90	2

NOTES: (1) All draw forged to 2" square bar.

(2) 8 hour second step age (MA58) and 16 hour second step age (MA39) from earlier work on this contract was also used (Table 19).

TABLE 13

FABRICATING CONDITIONS (1) AND FORGING NUMBERS OF PIECES SUBJECTED TO OXYGEN ANALYSES

	Preheat Temperature	Forging Numbers Preheat Time (Hrs.) 1	5	20	Number of Furnace Door Opens Prior to this Compact Preheat Time (Hrs.) 1	5	20
MA58 Alloy (2)	900	E1	J1	H1	0	8	11
	950	E2	A13	H2	0	1	8
	1000	– (4)		H3			5
MA39 Alloy (3)	900	E8	J5	H8	3	10	14
	950						
	1000			H9			3

NOTES:
(1) All draw forged to 2" square bar.
(2) Compacts cold pressed to 70% of theoretical density.
(3) Compacts cold pressed to 80% of theoretical density.
(4) Blank space in table indicates no oxygen determination.

TABLE 14

COMPOSITION OF EXTRUSIONS

Alloy	Material	Sample No.	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Be	Zr	Co	Oxygen
MA58	Fine Powder	395064 [a]	.04	.07	2.28	.00	2.20	.00	.00	5.83	.00	.000	.11		.39 [c]
MA58	Course Powder	395065 [a]	.04	.07	2.29	.00	2.26	.00	.00	5.79	.00	.000	.11		.28 [c]
MA39	Fine Powder	395066 [b]	.04	.06	.57	.00	3.66	.00	.01	8.98	.00		.00	.69	.4 [d]

NOTES: (a) Analytical Chemistry J.O. 70-112403 Remelt Analysis.

(b) Analytical Chemistry J.O. 70-061609 Melt Analysis.

(c) Analytical Chemistry J.O. 71-021009 (Neutron Activation Analysis).

(d) Estimated from Table 31.

TABLE 15

POWDER SIZE DISTRIBUTION OF POWDERS MADE INTO EXTRUSIONS

Sample Number	Material	Pot No.	(1) Standard Screen Size Distribution (%) -8+16	-16+30	-30+50	-50+100	-100+200	-200+325	-325	Date Atomized	Scalping Screen
395064	Fine Powder[2]	1393	0.0	0.0	0.0	0.0	2.0	14.6	83.2	6-11-70	100
395065	Coarse Powder[2]	1393	0.0	0.2	8.6	24.6	23.4	13.8	29.4	6-11-70	24
395066	Fine Powder[3]	1394	0.0	0.0	0.0	0.0	6.6	12.6	80.8	6-12-70	100

Sample Number	Micromesh Screen Size Distribution (% Less than Size Shown)[1] -175u	-150u	-125u	-105u	-90u	-75u	-60u	-45u	-30u	-20u	-15u	-10u	-5u
395064[2]	--	--	100	99	96	91	84	71	52	32	22	11	8
395065[2]	63	59	54	47	42	38	31	24	16	10	9	8	7

NOTE: (1) Analytical J.O. No. 70-112404.

(2) MA58 Alloy.

(3) MA39 Alloy.

TABLE 16

CRACKED METAL IN EACH P/M HAND FORGING (cubic inches)(1)(5)

Forging Series =	A	C	D	E	H	J	K	M
Forging Number								
1	65.0	17.4	17.9	14.5	12.7	30.9	10.3	4.8
2	25.9	25.3	17.9	12.6	14.6	8.2	11.8	14.6
3	11.0	48.5	12.1	10.3	8.9	20.1	6.9	5.4
4	7.8	17.4	13.4	18.5	14.2	6.6	17.0	4.8
5	52.1	105.4(3)	28.7	21.3	12.1	47.8	12.8	
6	37.1	103.0(4)	22.1	14.4	29.1	29.5	13.7	
7	28.9	112.1(3)	30.3	14.8	27.5	7.2	100.7(4)	
8	64.1	87.3	44.8(3)	63.9	18.0		11.2(2)	
9	22.5			15.4	11.4			
10	70.5			15.2			15.8	
11	41.3(4)			10.3				
12	56.7(4)			19.4				
13	10.3(2)			39.0(3)				
14	9.0(2)							

NOTES:
(1) Total billet volume (forging volume) = 140.5 cubic inches, except as noted.
(2) Total billet and forging volume = 134.5 cubic inches.
(3) End cracked during thermal treatments.
(4) Piece not completely forged because of severe cracking.
(5) See following Table 2 for Project B forging volumes.

TABLE 17

VOLUME OF CRACKED METAL AND METAL RECOVERY(4) FOR "B" FORGINGS (PROJECT B)

		3.25 inches square			2.0 inches square				1.25 inches square			
Alloy	Forg. Opr.	Forg. No.	Cracked Metal Volume(2) (cu. in.)	% Metal Rec.	Forg. No.	Forg. Volume (cu. in.)	Cracked Forg. Volume (cu. in.)	% Metal Rec.	Forg. No.	Forg. Volume (cu. in.)	Cracked Forg. Volume (cu. in.)	% Metal Rec.
MA58	Draw	B7	12	91	B4	88	0	100	B17	46	1.4	97
MA58	A(1)	B1	0	100	B5	88	0	100	B18	48	0.8	98
MA58	A-B(1)	B2	45	68	B6	92	5	95	B19	47	1.5	97
MA58	A-B-C(1)	B3	12	91	B15	82	7	91	B20	45	1.7	96
MA39	Draw	B14	20	86	B11	79	23	71	B21	51	6.1	88
MA39	A(1)	B8	57	59	B12	89	8(3)	92(3)	B22	52	1.3	98
MA39	A-B(1)	B9	56	60	B13	86	14	84	B23	50	1.0(3)	98(3)
MA39	A-B-C(1)	B10	54	62	B16	88	8	91	B24	40	1.7	96

NOTES: (1) Upset and draw.
(2) Forging volume = 140.5 cu. in.
(3) Failed SNT Class A, cracking visually estimated.
(4) $[100-(\frac{\text{Volume cracked}}{\text{Volume of forging}} \times 100)]$.

TABLE 18

PERCENT METAL RECOVERY OF EACH FORGING(1)

Forging Series *	A	C	D	E	H	J	K	M
Forging Number								
1	54	88	87	90	91	78	93	97
2	82	82	87	91	90	94	92	90
3	92	65	91	93	94	86	95	96
4	94	88	90	87	90	95	88	97
5	63	25	70	85	91	66	91	
6	74	26	84	90	79	79	90	
7	79	10	78	90	80	95	28	
8	54	38	68	54	87		92	
9	84			89	92		76	
10	50			89			89	
11	71			93				
12	60			86				
13	92			72				
14	93							

NOTES:
(1) $[100 - (\frac{\text{Volume cracked}}{\text{Volume of forging}} \times 100)]$.
(2) Overall metal recovery = 82%.
(3) "B" series forgings in Table 2.

TABLE 19

TENSILE PROPERTIES OF P/M HAND FORGINGS

SAMPLE NO.	ALLOY	LONGITUDINAL PROPERTIES T. S. (KSI)	Y. S. (KSI)	EL. (% IN 4D)	NTS/YS	TRANSVERSE PROPERTIES T. S. (KSI)	Y. S. (KSI)	EL. (% IN 4D)	NTS/YS
379614A1	MA58	70.5	62.9	18.0	1.41	66.5	58.2	6.0	.68
379614A2	MA58	72.3	64.3	16.0	1.46	67.5	57.4	8.0	1.09
379614A3	MA58	70.5	62.3	16.0	1.48	67.2	59.5	8.0	1.06
379614A4	MA58	74.0	65.9	18.0	1.37	71.9	63.9	6.0	1.09
379614A5	MA58	75.3	67.6	16.0	1.36	72.3	64.4	17.0	1.00
379614A6	MA58	71.9	63.0	12.0	1.45	73.5	65.5	13.0	.90
379614A13	MA58	74.3	67.6	16.0	1.31	72.1	64.7	9.0	.86
379614B1	MA58	74.5	68.9	15.0	1.31	73.4	67.4	9.0	.85
379614B2	MA58	75.3	69.3	21.0	1.25	71.4	63.8	12.0	.90
379614B3	MA58	76.0	69.5	16.0	1.34	72.3	65.4	9.0	.85
379614B4	MA58	75.3	69.4	17.0	1.34	74.8	67.1	8.0	.89
379614B5	MA58	76.7	70.1	15.0	1.39	73.7	66.8	10.0	.85
379614B6	MA58	77.0	70.3	16.0	1.37	74.3	66.9	14.0	.83
379614B7	MA58	75.5	69.0	14.0	1.27	73.9	66.4	9.0	.65
379614B15	MA58	74.5	67.8	8.0	1.40	72.4	65.8	7.0	.88
379614B17	MA58	76.9	71.9	16.0	1.34	76.7	70.6	11.0	
379614B18	MA58	77.9	72.0	16.0	1.28	75.9	69.7	12.0	
379614B19	MA58	77.6	71.4	16.0	1.31	76.5	70.4	8.0	
379614B20	MA58	76.3	71.1	16.0	1.31	75.6	69.1	8.0	
379614B25	MA58	72.8	65.2	19.0	1.41	68.5	59.3	11.0	.84
379614C1	MA58	74.0	66.9	18.0	1.37	73.2	65.3	11.0	.72
379614C2	MA58	73.7	66.1	19.0	1.31	73.3	65.3	6.0	.72
379614C3	MA58	74.0	66.8	16.0	1.36	69.6	60.5	7.0	.83
379614C4	MA58	73.3	66.1	16.0	1.34	68.9	60.0	7.0	.94
379614D1	MA58	75.5	68.3	18.0	1.32	73.4	64.4	12.0	.73

(CONTINUED)

TABLE 19

TENSILE PROPERTIES OF P/M HAND FORGINGS

SAMPLE NO.	ALLOY	LONGITUDINAL PROPERTIES T. S. (KSI)	Y. S. (KSI)	EL. (% IN 4D)	NTS/YS	TRANSVERSE PROPERTIES T. S. (KSI)	Y. S. (KSI)	EL. (% IN 4D)	NTS/YS
379614D2	MA58	75.9	67.8	13.0	1.28	72.8	66.0	5.0	.81
379614D3	MA58	75.3	67.2	16.0	1.28	70.0	62.5	6.0	.83
379614D4	MA58	74.9	68.0	18.0	1.38	72.1	64.3	11.0	.93
379614E1	MA58	75.7	67.4	14.0	1.43	72.7	64.0	11.0	1.09
379614E2	MA58	76.6	69.4	15.0	1.35	75.3	65.3	11.0	.93
379614E3	MA58	72.9	65.5	16.0	1.45	70.4	61.1	12.0	.86
379614E4	MA58	75.3	67.6	15.0	1.42	74.3	65.1	12.0	.75
379614E5	MA58	77.3	69.5	16.0	1.35	72.7	63.5	8.0	.85
379614E10	MA58	73.1	65.4	18.0	1.43	72.0	62.9	14.0	.71
379614E11	MA58	75.7	67.7	16.0	1.38	72.8	63.3	12.0	.88
379614H1	MA58	76.1	68.2	16.0	1.23	71.4	63.6	7.0	.60
379614H2	MA58	77.2	69.1	14.0	1.24	70.2	63.2	6.0	.58
379614H3	MA58	76.6	69.4	16.0	1.33	74.5	66.4	8.0	.86
379614H4	MA58	73.3	65.2	15.0	1.35	69.3	60.8	6.0	.81
379614H5	MA58	73.9	66.4	17.0	1.35	68.8	60.3	16.0	.79
379614J1	MA58	76.6	68.3	14.0	1.34	70.0	62.3	6.0	.65
379614J2	MA58	76.4	69.2	16.0	1.34	73.4	64.5	12.0	.84
379614J3	MA58	73.9	66.5	16.0	1.33	71.1	63.0	8.0	.64
379614J4	MA58	73.3	65.9	16.0	1.41	71.2	62.7	13.0	.77
379614J7	MA58	73.9	66.4	16.0	1.34	71.5	63.2	5.0	.84
379614K1	MA58	73.9	67.2	18.0	1.42	72.4	64.8	8.0	1.20
379614K2	MA58	74.5	66.0	16.0	1.43	71.6	62.6	8.0	.97
379614K3	MA58	76.4	69.0	17.0	1.34	73.9	65.4	8.0	.68
379614K7	MA58	73.3	66.8	16.0	1.40	70.9	64.0	8.0	1.00
379614K8	MA58	74.4	68.1	16.0	1.31	75.0	67.9	7.0	.89
	AVG.	74.85	67.62	16.00	1.36	72.2	64.2	9.32	.846
	Σ DEV.^{2}	146.30	232.78	184.00	0.17	273.85	419.8	404.88	.84
STD.	DEV	1.73	2.18	1.93	0.58	2.30	2.93	2.87	.14

TABLE 20

TENSILE PROPERTIES OF P/M HAND FORGINGS

		LONGITUDINAL PROPERTIES				TRANSVERSE PROPERTIES			
SAMPLE NO.	ALLOY	T. S. (KSI)	Y. S. (KSI)	EL. (% IN 4D)	NTS/YS	T. S. (KSI)	Y. S. (KSI)	EL. (% IN 4D)	NTS/YS
379615A7	MA39	75.1	65.3	13.0	1.25	70.6	61.8	6.0	.65
379615A8	MA39	72.8	63.0	15.0	1.26	71.7	61.6	6.0	.62
379615A9	MA39	73.7	63.8	14.0	1.26	70.8	61.6	7.0	.78
379615A10	MA39	74.5	64.4	14.0	1.19	72.0	62.4	7.0	.79
379615A14	MA39	73.3	62.3	15.0	1.29	69.7	59.3	7.0	.81
379615B8	MA39	75.7	66.7	14.0	1.24	72.4	63.3	4.0	.72
379615B9	MA39	74.3	66.0	16.0	1.20	72.1	62.5	7.0	.84
379615B10	MA39	74.6	65.8	16.0	1.28	73.8	62.9	10.0	.85
379615B11	MA39	76.7	67.5	16.0	1.23	73.9	65.8	8.0	.75
379615B12	MA39	76.4	68.1	16.0	1.27	74.0	65.1	6.0	.79
379615B13	MA39	76.7	68.1	15.0	1.22	74.5	65.1	9.0	.86
379615B14	MA39	76.4	68.4	13.0	1.15	73.9	64.5	10.0	.70
379615B16	MA39	75.9	67.4	16.0	1.22	75.3	68.1	4.0	.74
379615B21	MA39	77.3	68.8	16.0	1.23	75.9	68.2	6.0	
379615B22	MA39	77.1	67.2	18.0	1.25	71.3	63.9	4.0	
379615B23	MA39	77.5	69.2	16.0	1.11	75.5	66.4	10.0	
379615B24	MA39	76.6	68.1	16.0	1.21	73.4	63.3	10.0	
379615B26	MA39	73.1	64.3	16.0	1.29	70.7	61.8	5.0	.75
379615C5	MA39	74.1	63.8	16.0	1.26	69.2	60.6	4.0	.75
379615C7	MA39	71.6	61.8	14.0	1.34	67.2	59.8	5.0	.75
379615C8	MA39	74.5	64.9	16.0	1.19	73.4	63.3	12.0	.75
379615D5	MA39	74.0	64.5	16.0	1.25	71.1	61.7	4.0	.79
379615D6	MA39	74.9	65.5	15.0	1.21	73.5	63.0	8.0	.76
379615D7	MA39	73.5	64.3	16.0	1.30	71.3	60.9	10.0	.71
379615D8	MA39	76.0	67.2	16.0	1.25	73.1	63.6	8.0	.81

(CONTINUED)

TABLE 20

TENSILE PROPERTIES OF P/M HAND FORGINGS

SAMPLE NO.	ALLOY	LONGITUDINAL PROPERTIES T. S. (KSI)	Y. S. (KSI)	EL. (% IN 4D)	NTS/YS	TRANSVERSE PROPERTIES T. S. (KSI)	Y. S. (KSI)	EL. (% IN 4D)	NTS/YS
379615E6	MA39	75.3	65.5	16.0	1.25	73.7	63.6	8.0	.85
379615E7	MA39	73.0	63.2	16.0	1.25	72.1	61.3	10.0	.73
379615E8	MA39	73.6	64.1	13.0	1.32	70.9	59.2	11.0	1.00
379615E9	MA39	74.4	65.8	16.0	1.29	73.4	62.5	8.0	.85
379615E12	MA39	75.9	66.4	14.0	1.24	73.5	64.5	5.0	.76
379615E13	MA39	75.0	65.8	9.0	1.27	72.8	61.8	8.0	.66
379615H6	MA39	73.0	62.5	15.0	1.23	72.0	61.6	12.0	.47
379615H7	MA39	75.6	65.8	14.5	1.11	73.4	63.8	8.0	.65
379615H8	MA39	74.9	65.0	15.0	1.16	71.2	61.6	6.0	.67
379615H9	MA39	75.4	66.5	14.0	1.16	72.4	61.2	9.0	.83
379615J5	MA39	73.1	61.3	16.0	1.25	70.2	59.8	7.5	.91
379615J6	MA39	74.9	65.8	16.0	1.20	71.2	60.9	12.0	.86
379615K4	MA39	74.7	64.8	14.0	1.22	72.9	61.6	6.0	.85
379615K5	MA39	74.9	64.5	14.0	1.21	69.7	59.4	4.0	.90
379615K6	MA39	76.9	67.3	13.0	1.10	74.7	63.6	8.0	.83
379615K9	MA39	75.8	65.5	15.0	1.07	71.3	61.6	6.0	.81
379615K10	MA39	75.3	64.4	16.0	1.14	72.7	60.5	6.0	.79
	AVG.	74.95	65.49	15.02	1.22	72.3	62.6	7.42	.77
	Σ DEV.^{2}	80.22	152.94	89.24	0.15	134.96	188.96	227.98	.329
STD.	DEV.	1.40	1.93	1.48	0.06	1.81	2.15	2.358	.09

TABLE 21

EFFECT OF ALLOY ON QUALITY OF 2" x 2" HAND FORGINGS(1)

Green Density (%)	Preheat Temp. (°F)	Preheat Time (hr)	Hot Coin Pressure (ksi)	% Metal Recovery MA58	% Metal Recovery MA39	No. of Discontinuities MA58	No. of Discontinuities MA39
Uniaxial Cold Compact							
70	900	1	90	90	90	5	1
70	900	20	90	91	79	3	1
70	950	5	30	88	25	2	0
70	950	5	60	87	70	4	1
70	950	5	90	92	93	3	0
70	1000	1	90	93	90	4	2
70	1000	20	90	94	80	0	0
80	900	5	30	88	26	2	0
80	900	5	60	87	84	6	0
80	900	1	90	87	54	1	1
80	900	5	90	86	66	1	0
80	900	20	90	90	87	1	0
80	950	5	30	66	10	2	0
80	950	5	50	91	78	0	2
80	950	5	90	100	71	1	0
80	1000	5	30	88	38	0	0
80	1000	5	60	90	68	6	0
80	1000	1	90	85	90	1	0
80	1000	5	90	95	79	3	1
80	1000	20	90	91	92	1	0
Isostatic Cold Compact							
70	950	5	30	28	76	0	1
70	950	5	60	92	89	0	0
70	950	5	90	93	91	5	1
			Avg.	86.6	70.7	2.2	0.5

NOTES: (1) Draw forged bars.

TABLE 22

EFFECT OF ALLOY ON TENSILE PROPERTIES

		Longitudinal Properties				Transverse Properties			
Alloy	No. of Forgings	Tensile Strength (ksi)	Yield Strength (ksi)	Elon-gation (% in 4D)	NTS/YS	Tensile Strength (ksi)	Yield Strength (ksi)	Elon-gation (% in 4D)	NTS/YS
MA58	50	74.8	67.6	15.9	1.35	72.2	64.2	9.3	0.85 (1)
MA39	42	75.0	65.5	14.9	1.22	72.3	62.6	7.4	0.77 (2)
Student's t =			t = 4.90	t = 2.50	t = 6.50		t = 2.94	t = 3.42	t = 3.03
P =			>99.5%	99%	>99.5%		>99.5%	>99.5%	>99.5%

Notes: (1) 46 Forgings

(2) 38 Forgings

(3) P = Probability that the difference between averages is significant.

TABLE 23

EFFECT OF GREEN DENSITY ON QUALITY OF 2" x 2" HAND FORGINGS

Alloy	Preheat Temp. (°F)	Preheat Time (Hrs)	Hot Compact Pressure (ksi)	% Metal Recovery (2) 70% Density	% Metal Recovery (2) 80% Density	No. of Discontinuities 70% Density	No. of Discontinuities 80% Density
MA58	900	5	90	78	86	2	1
MA58	950	5	30	88	66	2	2
MA58	950	5	60	87	91	4	0
MA58	950	5	90	92	100	3	1
MA58	1000	5	90	94	95	3	3
	Averages			88	88	2.8	1.4
MA39	950	5	30	25	10	0	0
MA39	950	5	60	70	78	1	2
MA39	950	5	90	93	71	0	0
	Averages			66	53	0.3	0.7
Overall	Averages			78	75	1.9	1.1

NOTES: (1) Draw forged to 2" square.

(2)

Density	n	Avg.	$\Sigma dev.^2$
70%	8	78	3750
80%	8	75	5720

$t_{student's} = 0.28$ Prob. of signif. of difference <0.7

TABLE 24

EFFECT OF GREEN DENSITY ON PROPERTIES(1)
OF 2" SQUARE HAND FORGINGS

	Green Density	Longitudinal Properties: Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 4D)	Notched Tensile Strength (ksi)	Transverse Yield Strength: Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 4D)	Notched Tensile Strength (ksi)
MA58 Alloy	70%	74.4	66.4	14.8	91.3	72.2	64.1	10.2	52.4
	80%	74.6	66.8	16.3	90.8	70.5	61.7	9.4	49.8
	"P" (2)	<90%	<90%	95%	<90%	98.5%	99.5%	<90%	<90%
MA39 Alloy	70%	74.1	64.0	15.5	78.7	71.6	61.7	7.2	44.6
	80%	73.8	64.5	14.9	78.9	71.5	61.3	8.0	48.2
	"P"	<90%	<90%		<90%	<90%	<90%	<90%	<90%

NOTES: (1) Summarized from Tables 1, 2, 3 and 4, Appendix III.

(2) P = probability that difference between averages is significant.

TABLE 25

EFFECT OF COLD COMPACTING METHOD ON QUALITY OF 2" X 2" HAND FORGINGS

Alloy	Hot Compact Pressure (ksi)	% Metal Recovery: Isostatic Cold Compacting	% Metal Recovery: Uniaxial Cold Compacting	No. of Discontinuities: Isostatic Cold Compacting	No. of Discontinuities: Uniaxial Cold Compacting
MA58	30	28	88	0	2
MA58	60	92	87	0	4
MA58	90	93	92	5	3
MA39	30	76	25	1	0
MA39	60	89	80	0	1
MA39	90	91	93	1	0
	AVERAGE	78	78	1.1	1.7

NOTES: (1) Green Density = 70%
(2) Preheat Time = 5 hours
(3) Preheat Temp. = 950 F
(4) Draw Forged to 2" x 2"

TABLE 26

SUMMARY OF THE EFFECT OF COLD COMPACT METHOD ON PROPERTIES OF MA58 AND MA39 FORGINGS[1]

		LONGITUDINAL PROPERTIES				TRANSVERSE PROPERTIES			
		T.S.	Y.S.	El.	NTS/YS	T.S.	Y.S.	El.	NTS/YS
MA58 Alloy	Uniaxial	74.6	67.6	17.3	1.33	72.9	64.8	10.7	0.77
	Isostatic	73.9	67.4	16.7	1.38	72.7	65.5	7.7	1.03
	"p"(2)	<90%	<90%	<90%	<90%	99%	98%	99%	97%
MA39 Alloy	Uniaxial	73.8	63.5	15.7	1.27	70.0	60.6	5.0	0.78
	Isostatic	75.3	64.8	15.0	1.14	71.2	60.5	5.3	0.83
	"p"(2)	<90%	96%	<95%	<90%	97%	<90%	97%	<90%

Ref: (1) From Tables 5 and 6, Appendix III.

(2) Probability that differences in properties are significant.

TABLE 27

EFFECT OF PREHEAT TEMPERATURE ON QUALITY OF 2" X 2" FORGINGS

Alloy	Green Density (%)	Preheat Time (Hours)	Hot Compact Pressure (ksi)	% Metal Recovery Preheat Temperature 900 F	950 F	1000 F	No. of Discontinuities Preheat Temperature 900 F	950 F	1000 F
MA58	70	1	90	90	91	93	5	2	4
	70	5	90	78	92	94	2	3	3
	70	20	90	91	90	94	3	0	0
	80	5	90	86	100	95	1	1	3
	80	5	30	82	66	88	2	2	0
	80	5	60	87	91	90	6	0	6
			AVERAGE	86	88	92	3.2	1.3	2.7
MA39	80	5	90	66	71	79	0	0	1
	80	5	60	84	78	68	0	2	0
			AVERAGE	75	75	72	0	1	0.5
			OVERALL AVERAGE	80	85	91	2.4	1.2	2.1

NOTES: (1) Uniaxial Cold Compacts
(2) Draw Forged to 2" x 2"

TABLE 28

EFFECT OF PREHEAT TEMPERATURE ON AVERAGE TENSILE PROPERTIES OF 2" SQUARE HAND FORGINGS (1)

Alloy	Preheat Temp. ($^{\circ}$F)	Longitudinal Properties T.S. (ksi)	Longitudinal Y.S. (ksi)	Longitudinal El. (% in 4D)	Longitudinal NTS (ksi)	Longitudinal NTS/YS	Transverse Properties T.S. (ksi)	Transverse Y.S. (ksi)	Transverse El. (% in 4D)	Transverse NTS (ksi)	Transverse NTS/YS
MA58	900	75.3	67.4	15.3	89.0	1.32	72.1	64.0	7.3	48.2	0.75
	950	75.1	67.8	14.5	89.7	1.32	71.0	62.6	8.3	50.9	0.81
	1000	74.6	67.3	16.3	92.6	1.38	71.5	63.2	10.7	54.6	0.87
	P(2)			98%	98%				97.5%		
	P(3)				98%				>99.5%	95%	
MA39	900	74.0	63.4	15.5	78.0	1.23	71.8	61.4	7.8	51.1	0.83
	950	75.1	65.9	16.0	83.4	1.27	70.9	61.4	6.7	44.6	0.73
	1000	75.5	66.5	16.0	81.4	1.22	72.2	62.2	10.0	52.0	0.83
	P(2)								92%(4)	97%(4)	
	P(3)	95.5%	99.5%	<90%	<95%		90%	<90%	<90%	<90%	

NOTES:
(1) From Tables 7, 8, 9 and 10, Appendix III.
(2) Probability that 1000°F is significantly different than 950°F.
(3) Probability that 1000°F is significantly different than 900°F.
(4) Partial comparison -n = 4.

TABLE 29

EFFECT OF PREHEAT TIME ON QUALITY OF FORGINGS

Alloy	Green Density (%)	Preheat Temp. (°F)	% Metal Recovery(4) Preheat Time 1 (Hr.)	5 (Hr.)	20 (Hr.)	No. of Discontinuities Preheat Time 1 (Hr.)	5 (Hr.)	20 (Hr.)
MA58	70	900	90	78	91	5	2	3
MA58	70	950	91	92	90	2	3	0
MA58	70	1000	93	94	94	4	3	0
MA58	80	900	87	86	90	1	1	1
MA58	80	1000	85	95	91	1	3	1
MA39	80	900	54	66	87	1	0	0
MA39	80	1000	89	79	92	0	1	0
		AVERAGE	84	84	91	2	1.9	0.7

NOTES: (1) Uniaxial Cold Compact
(2) Draw Forged to 2" x 2"
(3) Hot Compact Pressure of 90 ksi
(4)

Preheat	n	Avg.	Σ dev.^{2}
5 hours	7	84	689
20 hours	7	91	25

student's = 1.5

Prob. of signif. of difference <0.95

TABLE 30

EFFECT OF PREHEAT TIME ON AVERAGE TENSILE PROPERTIES OF 2" SQUARE HAND FORGINGS[1]

		Longitudinal Properties					Transverse Properties				
Alloy	Preheat Time	T.S. (ksi)	Y.S. (ksi)	El. (% in 4D)	NTS (ksi)	NTS/YS	T.S. (ksi)	Y.S. (ksi)	El. (% in 4D)	NTS (ksi)	NTS/YS
MA58	1	75.6	67.9	15.2	95.0	1.40	73.1	63.8	10.8	57.6	0.90
	5	74.9	67.5	15.6	91.1	1.35	71.7	63.4	10.0	47.8	0.75
	20	75.4	67.7	15.6	88.0	1.30	70.4	62.9	8.7	45.7	0.74
	P[2]				All >98%				90%	99.5%	
MA39	1	74.0	64.9	14.5	84.8	1.31	72.2	60.9	9.5	56.0	0.92
	5	74.0	63.6	16.0	77.8	1.22	70.7	60.4	9.8	53.3	0.88
	20	75.2	65.8	14.5	76.4	1.16	71.8	61.4	7.5	45.8	0.75
	P[2]			<90%	99.5%				<90%	99.5%	

NOTES: (1) From Tables 11, 12, 13 and 14, Appendix III.

(2) Probability that 1 hour is significantly different from 20 hours.

TABLE 31

OXYGEN CONTENT OF MA58 AND MA39 P/M FORGINGS AS A FUNCTION OF COMPACT PREHEAT TIME AND TEMPERATURE

Alloy	Preheat Temp. (°F)	Preheat Time 1 Hr.	Preheat Time 5 Hr.	Preheat Time 20 Hr.	Preheat Time 1 Hr.	Preheat Time 5 Hr.	Preheat Time 20 Hr.
		Oxygen Content (Wt. %)			Vol. % MgO		
MA58	900°	.323	.338	.338	.59	.62	.62
6.0 Zn-2.3 Mg-2.3 Cu-0.11 Zr	950°	.339	.337	.322	.62	.62	.59
70% Green Density	1000°	--	--	.322	--	--	.59
MA39	900°	.367	.371	.384	.67	.68	.71
9.0 Zn-3.5 Mg-0.6 Cu-0.75 Co	950°	--	--	--	--	--	--
80% Green Density	1000°	--	--	.387	--	--	.71

Precision of oxygen measurements = ± 0.018%.

Vol. % MgO calculated from oxygen data.

TABLE 32

OSTWALD RIPENING OF Co_2Al_9 PHASE DURING PREHEAT OF MA39 COMPACTS

	Preheat Temp.	Preheat Time 1 Hr.	5 Hr.	20 Hr.
Average Particle Dia. (μ)	900°	0.40	0.65	0.80
	1000°	0.65	1.10	1.50
Average Dia. of 5 Largest Particles (μ)	900°	2.20	3.30	3.60
	1000°	2.75	4.70	6.85
Inter-Particle Spacing (μ) (Linear Measurement)	900°	2.60	3.30	9.50
	1000°	3.15	5.50	7.35

Compacts preheated in flowing argon atmosphere, hot pressed at 90 ksi, forged into 2" x 2" bar, solution heat treated 2 hrs. at 920°F, cold water quenched.

TABLE 33

EFFECT OF HOT COMPACT PRESSURE ON QUALITY OF FORGINGS

Alloy	(1) Green Density (%)	Preheat Time (Hr.)	Preheat Temp. (°F)	% Metal Recovery(4) Hot Compact Pressure 30 (ksi)	60 (ksi)	90 (ksi)	Number of Discontinuities Hot Compact Pressure 30 (ksi)	60 (ksi)	90 (ksi)
MA58	70	5	950	88	87	92	2	4	3
MA58	80	5	900	82	87	86	2	6	1
MA58	80	5	950	65	91	100	2	0	1
MA58	80	5	1000	88	90	95	0	6	3
MA58	70(2)	5	950	28	92	93	5	0	0
MA39	70	5	950	25	70	93	0	1	0
MA39	80	5	950	10	78	71	0	2	0
MA39	80	5	1000	38	68	79	0	0	1
MA39	70(2)	5	950	76	89	91	1	1	0
			AVERAGE	56	84	89	1.2	2.2	1

NOTES: (1) Uniaxial Cold Compact Except as Noted.
(2) Isostatic Cold Compact.
(3) Draw Forged to 2" x 2"

(4) Hot Compact Press →

	30 ksi	60 ksi	90 ksi
n	9	9	9
Avg.	56	84	89
Σ dev.^{2}	3291	675	634

$\tau = 2.21^{(5)}$ $\rho > 0.975$ $\tau = 1.22^{(5)}$ $\rho < 0.90$

(5) Student's τ - ρ = probability that difference in averages is significant.

TABLE 34

EFFECT OF HOT COMPACTING PRESSURE ON AVERAGE TENSILE PROPERTIES OF 2" SQUARE HAND FORGINGS(1)

Alloy	Hot Compacting Pressure	Longitudinal Properties T.S. (ksi)	Y.S. (ksi)	El. (% in 4D)	NTS (ksi)	NTS/YS	Transverse Properties T.S. (ksi)	Y.S. (ksi)	El. (% in 4D)	NTS (ksi)	NTS/YS
MA58	30	73.7	66.5	17.0	90.2	1.37	71.2	62.8	7.8	52.8	.84
	60	75.2	67.9	16.2	89.1	1.31	72.7	65.0	8.2	54.4	.84
	90	73.6	66.5	17.0	91.5	1.38	71.1	62.9	9.8	54.5	.87
MA39	30	74.0	64.0	15.2	77.5	1.21	70.3	61.0	6.8	46.8	.77
	60	74.7	65.1	16.0	8C.4	1.23	72.1	61.7	6.6	47.8	.78
	90	74.2	64.2	15.2	80.0	1.25	70.3	60.4	7.0	49.9	.83

NCTE: (1) From Tables 15, 16, 17 and 18, Appendix XII.

TABLE 35

EFFECT OF FORGING TEMPERATURE ON VISUALLY OBSERVED CRACKING ON 2" x 2" x 30" HAND FORGINGS (PROJECT A)

379614 (MA58) (3)

	Forging Temperature				
	550 F	600 F	650 F	700 F	750 F
End Cracking	1 slight (2)	1 slight	none	1 medium	2 medium
Edge Cracking	none	none	none	2 medium	3 slight
Face Cracking	1 slight	none	1 medium	1 medium	4 slight

379615 (MA39)

	Forging Temperature				
	550 F (3)	600 F (1)	650 F (4)	700 F (4)	750 F (4)
End Cracking	none		2 medium	1 slight	1 medium
Edge Cracking	4-2 severe (5)		none	none	none
Face Cracking	1 very severe		3 medium	1 slight	3-2 severe

NOTES:
(1) No forging prepared at 600 F.
(2) Number of surfaces cracked, cracking severity.
(3) Forged by squaring, then A-B Upset and Draw to 2" sq. bar.
(4) Forged by A Upset and Drawn to 2" sq. bars.
(5) Number of surfaces cracked, number severely cracked.

TABLE 36

EFFECT OF FORGING TEMPERATURE ON QUALITY OF HAND FORGINGS (PROJECT A)

	Alloy	Forging Temperature (°F)				
		550	600	650	700	750
Per Cent Metal Recovery	MA58(2)	94	92	74	82	54
	MA39(3)	60(2)	(1)	79	84	54
	Average	77		76	83	54
Number of Isolated Discontinuities	MA58(2)	3	3	4	3	2
	MA39(3)	(2)	(1)	2	0	1

NOTES:
(1) No forgings prepared at 600 F.
(2) Forged by squaring, then A-B upset and draw to 2" sq. bar.
(3) Forged by A upset and Draw to 2" sq. bars.
(4) Cold Pressed to 70% density by uniaxial compacting.
(5) Preheated 5 hours at 950 F.
(6) Hot compacted by pressing at 90 ksi.

TABLE 37

EFFECT OF FORGING TEMPERATURE
ON LONGITUDINAL PROPERTIES

TENSILE STRENGTH

ALLOY	FORGING TEMPERATURE 550	600	650	700	750
ALCOA MA58	74050.	70500.	71850.	72300.	70500.
ALCOA MA39			75150.	73650.	72800.

YIELD STRENGTH

ALLOY	FORGING TEMPERATURE 550	600	650	700	750
ALCOA MA58	65950.	62350.	62950.	64300.	62900.
ALCOA MA39			65300.	63800.	63000.

ELONGATION

ALLOY	FORGING TEMPERATURE 550	600	650	700	750
ALCOA MA58	18.0	16.0	12.0	16.0	18.0
ALCOA MA39			13.0	14.0	15.0

NOTCH TENSILE STRENGTH-YIELD STRENGTH RATIO

ALLOY	FORGING TEMPERATURE 550	600	650	700	750
ALCOA MA58	1.37	1.48	1.45	1.46	1.41
ALCOA MA39			1.25	1.26	1.26

TABLE 38

EFFECT OF FORGING TEMPERATURE ON TRANSVERSE PROPERTIES

TENSILE STRENGTH

ALLOY	FORGING TEMPERATURE 550	600	650	700	750
ALCOA MA58	71950.	67200.	73500.	67500.	66500.
ALCOA MA39			70600.	70800.	71750.

YIELD STRENGTH

ALLOY	FORGING TEMPERATURE 550	600	650	700	750
ALCOA MA58	63900.	59500.	65550.	57450.	58200.
ALCOA MA39			61800.	61600.	61650.

ELONGATION

ALLOY	FORGING TEMPERATURE 550	600	650	700	750
ALCOA MA58	6.0	8.0	13.0	8.0	6.0
ALCOA MA39			6.0	7.0	6.0

NOTCH TENSILE STRENGTH-YIELD STRENGTH RATIO

ALLOY	FORGING TEMPERATURE 550	600	650	700	750
ALCOA MA58	1.09	1.06	.90	1.09	.68
ALCOA MA39			.65	.78	.62

TABLE 39

EFFECT OF FORGING PROCEDURE ON FORGING VISUAL QUALITY (PROJECT B)

	Forging Operation	379614 (MA58) 3.25" sq.	2" sq.	1.25" sq.
End Cracking	Draw	1 severe (1)	none	1 medium
	A	none	none	none
	A-B	1 slight	1 severe	1 slight
	A-B-C	1 slight	(2)	
Edge Cracking	Draw	none	none	none
	A	none	none	none
	A-B	none	none	none
	A-B-C	1 slight	(2)	
Face Cracking	Draw	none	none	none
	A	1 slight	none	none
	A-B	3-1 severe	none	none
	A-B-C	1 slight	(2)	
		379615 (MA39)		
End Cracking	Draw	2-1 severe (3)	1 severe	1 severe
	A	none	1 medium	1 medium
	A-B	2 slight	1 medium	1 medium
	A-B-C	none	(2)	
Edge Cracking	Draw	none	none	none
	A	none	none	none
	A-B	4 medium	none	none
	A-B-C	4 severe	(2)	
Face Cracking	Draw	none	none	none
	A	2 severe	4-1 severe	2 medium
	A-B	2-1 severe	3-1 severe	none
	A-B-C	1 severe	(2)	

NOTES:
(1) Number of surfaces cracked, cracking severity.
(2) Forgings being prepared.
(3) Number of surfaces cracked, number severely cracked.

TABLE 40

EFFECT OF FORGING PROCEDURE ON FORGING QUALITY

Alloy	Forging Operation	% Metal Recovery (5,6) Final Forging Section Size 3.25" sq.	2.0" sq.	1.25" sq.	Avg.	No. of Discontinuities Final Forging Section Size 3.25" sq.	2.0" sq.	1.25" sq.
MA58	Draw	91	100	97	96	0	1	0
MA58	A Upset & Draw	100	100	98	99	1	3	0
MA58	A-B Upset & Draw	68	95	97	87	0	1	0
MA58	A-B-C Upset & Draw	91	91	96	93	1	0	0
	AVERAGE	88	96	97		0.5	1.25	0
MA39	Draw	86	71	88	82	0	0	0
MA39	A Upset & Draw	59	92(4)	98	83	0	(4)	0
MA39	A-B Upset & Draw	60	84	98(4)	81	0	1	(4)
MA39	A-B-C Upset & Draw	62	91	96	83	0	0	0
	AVERAGE	66	85	95		0.0	----	---

NOTES:

(1) Compacts cold pressed to 80% density.
(2) Preheated 5 hours at 950 F.
(3) Hot compacted at 90 ksi.
(4) Failed SNT Class A - Quality rated by visual cracks detected.

(5)

	3.25 sq.	2.0 sq.	1.25 sq.	Draw	A Upset & Draw	A-B Upset & Draw	A-B-C Upset & Draw
MA 58							
Avg.	88	96	97	96	99	87	93
Σ dev.^{2}	567	59	3	38	2	521	19
MA39							
Avg.	66	85	95				
Σ dev.^{2}	505	262	65				

MA 58 (3.25 sq. vs. 2.0 sq.): $\tau = 1.22$, $\rho < 0.8$

MA 58 (Draw vs. A Upset & Draw): $\tau = 0.66$, $\rho < 0.7$

MA 58 (A Upset & Draw vs. A-B Upset & Draw): $\tau = .49$, $\rho < 0.7$

MA 58 (A-B Upset & Draw vs. A-B-C Upset & Draw): $\tau = 0.52$, $\rho < 0.7$

MA39 (3.25 sq. vs. 2.0 sq.): $\tau = 2.4$, $\rho = 0.975$

MA39 (2.0 sq. vs. 1.25 sq.): $\tau = 1.95$, $\rho = 0.95$

(6) Student's τ - ρ = probability that differences between averages are significant.

TABLE 41

EFFECT OF TYPE AND AMOUNT OF DEFORMATION
ON LONGITUDINAL PROPERTIES

TENSILE STRENGTH - ALCOA MA58

DEFORMATION METHOD	3.25 X 3.25	FINISHED SIZE 2.00 X 2.00	1.25 X 1.25
DRAW ONLY	75500.	75250.	76850.
A UPSET AND DRAW	74550.	76700.	77900.
A-B UPSET AND DRAW	75300.	77050.	77650.
A-B-C UPSET AND DRAW	76050.	74550.	76350.

YIELD STRENGTH - ALCOA MA58

DEFORMATION METHOD	3.25 X 3.25	FINISHED SIZE 2.00 X 2.00	1.25 X 1.25
DRAW ONLY	69050.	69350.	71850.
A UPSET AND DRAW	68950.	70100.	72000.
A-B UPSET AND DRAW	69300.	70300.	71450.
A-B-C UPSET AND DRAW	69550.	67800.	71100.

ELONGATION - ALCOA MA58

DEFORMATION METHOD	3.25 X 3.25	FINISHED SIZE 2.00 X 2.00	1.25 X 1.25
DRAW ONLY	14.0	17.0	16.0
A UPSET AND DRAW	15.0	15.0	16.0
A-B UPSET AND DRAW	21.0	16.0	16.0
A-B-C UPSET AND DRAW	16.0	8.0	16.0

NOTCH TENSILE STRENGTH - YIELD STRENGTH RATIO - ALCOA MA58

DEFORMATION METHOD	3.25 X 3.25	FINISHED SIZE 2.00 X 2.00	1.25 X 1.25
DRAW ONLY	1.27	1.34	1.34
A UPSET AND DRAW	1.31	1.39	1.28
A-B UPSET AND DRAW	1.25	1.37	1.31
A-B-C UPSET AND DRAW	1.34	1.40	1.31

(CONTINUED)

TABLE 41

EFFECT OF TYPE AND AMOUNT OF DEFORMATION
ON TRANSVERSE PROPERTIES

TENSILE STRENGTH - ALCOA MA58

DEFORMATION METHOD	FINISHED SIZE 3.25 X 3.25	2.00 X 2.00	1.25 X 1.25
DRAW ONLY	73850.	74800.	76750.
A UPSET AND DRAW	73450.	73750.	75900.
A-B UPSET AND DRAW	71450.	74350.	76500.
A-B-C UPSET AND DRAW	72250.	72400.	75600.

YIELD STRENGTH - ALCOA MA58

DEFORMATION METHOD	FINISHED SIZE 3.25 X 3.25	2.00 X 2.00	1.25 X 1.25
DRAW ONLY	66400.	67100.	70600.
A UPSET AND DRAW	67400.	66800.	69750.
A-B UPSET AND DRAW	63750.	66950.	70400.
A-B-C UPSET AND DRAW	65400.	65850.	69100.

ELONGATION - ALCOA MA58

DEFORMATION METHOD	FINISHED SIZE 3.25 X 3.25	2.00 X 2.00	1.25 X 1.25
DRAW ONLY	9.0	8.0	11.0
A UPSET AND DRAW	9.0	10.0	12.0
A-B UPSET AND DRAW	12.0	14.0	8.0
A-B-C UPSET AND DRAW	9.0	7.0	8.0

NOTCH TENSILE STRENGTH - YIELD STRENGTH RATIO - ALCOA MA58

DEFORMATION METHOD	FINISHED SIZE 3.25 X 3.25	2.00 X 2.00	1.25 X 1.25
DRAW ONLY	.65	.89	
A UPSET AND DRAW	.85	.85	
A-B UPSET AND DRAW	.90	.83	
A-B-C UPSET AND DRAW	.85	.88	

TABLE 42

EFFECT OF TYPE AND AMOUNT OF DEFORMATION
ON LONGITUDINAL PROPERTIES

TENSILE STRENGTH - ALCOA MA39

DEFORMATION METHOD	FINISHED SIZE 3.25 X 3.25	2.00 X 2.00	1.25 X 1.25
DRAW ONLY	76450.	76700.	77300.
A UPSET AND DRAW	75750.	76450.	77100.
A-B UPSET AND DRAW	74250.	76750.	77500.
A-B-C UPSET AND DRAW	74600.	75850.	76600.

YIELD STRENGTH - ALCOA MA39

DEFORMATION METHOD	FINISHED SIZE 3.25 X 3.25	2.00 X 2.00	1.25 X 1.25
DRAW ONLY	68450.	67500.	68800.
A UPSET AND DRAW	66700.	68100.	67200.
A-B UPSET AND DRAW	66000.	68150.	69200.
A-B-C UPSET AND DRAW	65850.	67450.	68150.

ELONGATION - ALCOA MA39

DEFORMATION METHOD	FINISHED SIZE 3.25 X 3.25	2.00 X 2.00	1.25 X 1.25
DRAW ONLY	13.0	16.0	16.0
A UPSET AND DRAW	14.0	16.0	18.0
A-B UPSET AND DRAW	16.0	15.0	16.0
A-B-C UPSET AND DRAW	16.0	16.0	16.0

NOTCH TENSILE STRENGTH - YIELD STRENGTH RATIO - ALCOA MA39

DEFORMATION METHOD	FINISHED SIZE 3.25 X 3.25	2.00 X 2.00	1.25 X 1.25
DRAW ONLY	1.15	1.23	1.23
A UPSET AND DRAW	1.24	1.27	1.25
A-B UPSET AND DRAW	1.20	1.22	1.11
A-B-C UPSET AND DRAW	1.28	1.22	1.21

(CONTINUED)

TABLE 42

EFFECT OF TYPE AND AMOUNT OF DEFORMATION
ON TRANSVERSE PROPERTIES

TENSILE STRENGTH - ALCOA MA39

DEFORMATION METHOD	FINISHED SIZE 3.25 X 3.25	2.00 X 2.00	1.25 X 1.25
DRAW ONLY	73850.	73950.	75900.
A UPSET AND DRAW	72400.	74000.	71300.
A-B UPSET AND DRAW	72150.	74500.	75500.
A-B-C UPSET AND DRAW	73800.	75300.	73400.

YIELD STRENGTH - ALCOA MA39

DEFORMATION METHOD	FINISHED SIZE 3.25 X 3.25	2.00 X 2.00	1.25 X 1.25
DRAW ONLY	64450.	65850.	68200.
A UPSET AND DRAW	63350.	65100.	63950.
A-B UPSET AND DRAW	62550.	65050.	66450.
A-B-C UPSET AND DRAW	62900.	69100.	63300.

ELONGATION - ALCOA MA39

DEFORMATION METHOD	FINISHED SIZE 3.25 X 3.25	2.00 X 2.00	1.25 X 1.25
DRAW ONLY	10.0	8.0	6.0
A UPSET AND DRAW	4.0	6.0	4.0
A-B UPSET AND DRAW	7.0	9.0	10.0
A-B-C UPSET AND DRAW	10.0	4.0	10.0

NOTCH TENSILE STRENGTH - YIELD STRENGTH RATIO - ALCOA MA39

DEFORMATION METHOD	FINISHED SIZE 3.25 X 3.25	2.00 X 2.00	1.25 X 1.25
DRAW ONLY	.70	.75	
A UPSET AND DRAW	.72	.79	
A-B UPSET AND DRAW	.84	.86	
A-B-C UPSET AND DRAW	.85	.74	

TABLE 43

INTERACTIONS OF GREEN DENSITY, PREHEAT TIME AND TEMPERATURE AND ALLOY ON QUALITY OF FORGINGS

		Green Density = 70% Preheat Time (Hrs.)		Green Density = 80% Preheat Time (Hrs.)		
Alloy	Preheat Temp. (°F)	1	20	1	20	Average
Percent Metal Recovery						
MA58	900	90	91	87	90	89
MA58	1000	93	94	85	91	92
	AVERAGE	91	92	86	91	
MA39	900	90	79	54	87	78
MA39	1000	90	80	89	92	83
	AVERAGE	90	80	72	90	
	OVERALL AVERAGE	89	86	77	90	85
Number of Isolated Discontinuities						
MA58	900	5	3	1	1	
MA58	1000	4	0	1	1	
MA39	900	1	1	1	0	
MA39	1000	2	0	0	0	

NOTES: (1) Hot compacted at 90 ksi.
(2) Draw forged to 2" square.

TABLE 44

INTERACTIONS OF GREEN DENSITY, PREHEAT TIME, PREHEAT TEMPERATURE, ALLOY ON LONGITUDINAL PROPERTIES

TENSILE STRENGTH

ALLOY	PREHEAT TEMP.	GREEN DENSITY = 70% PREHEAT TIME 1 HR.	GREEN DENSITY = 70% PREHEAT TIME 20 HR.	GREEN DENSITY = 80% PREHEAT TIME 1 HR.	GREEN DENSITY = 80% PREHEAT TIME 20 HR.
ALCOA MA58	900	75700.	76100.	75250.	73300.
ALCOA MA58	1000	72900.	76600.	77350.	73850.
ALCOA MA39	900	75300.	73050.	73600.	74850.
ALCOA MA39	1000	73050.	75600.	74450.	75450.

YIELD STRENGTH

ALLOY	PREHEAT TEMP.	GREEN DENSITY = 70% PREHEAT TIME 1 HR.	GREEN DENSITY = 70% PREHEAT TIME 20 HR.	GREEN DENSITY = 80% PREHEAT TIME 1 HR.	GREEN DENSITY = 80% PREHEAT TIME 20 HR.
ALCOA MA58	900	67450.	68200.	67600.	65250.
ALCOA MA58	1000	65450.	69400.	69500.	66350.
ALCOA MA39	900	65500.	62550.	64050.	65000.
ALCOA MA39	1000	63150.	65750.	65750.	66550.

ELONGATION

ALLOY	PREHEAT TEMP.	GREEN DENSITY = 70% PREHEAT TIME 1 HR.	GREEN DENSITY = 70% PREHEAT TIME 20 HR.	GREEN DENSITY = 80% PREHEAT TIME 1 HR.	GREEN DENSITY = 80% PREHEAT TIME 20 HR.
ALCOA MA58	900	14.0	16.0	15.0	15.0
ALCOA MA58	1000	16.0	16.0	16.0	17.0
ALCOA MA39	900	16.0	15.0	13.0	15.0
ALCOA MA39	1000	16.0	14.5	16.0	14.0

NOTCH TENSILE STRENGTH - YIELD STRENGTH RATIO

ALLOY	PREHEAT TEMP.	GREEN DENSITY = 70% PREHEAT TIME 1 HR.	GREEN DENSITY = 70% PREHEAT TIME 20 HR.	GREEN DENSITY = 80% PREHEAT TIME 1 HR.	GREEN DENSITY = 80% PREHEAT TIME 20 HR.
ALCOA MA58	900	1.43	1.23	1.42	1.35
ALCOA MA58	1000	1.45	1.33	1.35	1.35
ALCOA MA39	900	1.25	1.23	1.32	1.16
ALCOA MA39	1000	1.25	1.11	1.29	1.16

TABLE 45

INTERACTIONS OF GREEN DENSITY, PREHEAT TIME, PREHEAT TEMPERATURE, ALLOY ON TRANSVERSE PROPERTIES

TENSILE STRENGTH

		GREEN DENSITY = 70%		GREEN DENSITY = 80%	
	PREHEAT	PREHEAT TIME			
ALLOY	TEMP.	1 HR.	20 HR.	1 HR.	20 HR.
ALCOA MA58	900	72750.	71450.	74300.	69250.
ALCOA MA58	1000	70450.	74500.	72750.	68800.
ALCOA MA39	900	73650.	72000.	70850.	71200.
ALCOA MA39	1000	72100.	73400.	73450.	72350.

YIELD STRENGTH

		GREEN DENSITY = 70%		GREEN DENSITY = 80%	
	PREHEAT	PREHEAT TIME			
ALLOY	TEMP.	1 HR.	20 HR.	1 HR.	20 HR.
ALCOA MA58	900	64000.	63550.	65150.	60850.
ALCOA MA58	1000	61050.	66400.	63500.	60300.
ALCOA MA39	900	63600.	61600.	59250.	61650.
ALCOA MA39	1000	61300.	63750.	62500.	61150.

ELONGATION

		GREEN DENSITY = 70%		GREEN DENSITY = 80%	
	PREHEAT	PREHEAT TIME			
ALLOY	TEMP.	1 HR.	20 HR.	1 HR.	20 HR.
ALCOA MA58	900	11.0	7.0	12.0	6.0
ALCOA MA58	1000	12.0	8.0	8.0	16.0
ALCOA MA39	900	8.0	12.0	11.0	6.0
ALCOA MA39	1000	10.0	8.0	8.0	9.0

NOTCH TENSILE STRENGTH - YIELD STRENGTH RATIO

		GREEN DENSITY = 70%		GREEN DENSITY = 80%	
	PREHEAT	PREHEAT TIME			
ALLOY	TEMP.	1 HR.	20 HR.	1 HR.	20 HR.
ALCOA MA58	900	1.09	.60	.75	.81
ALCOA MA58	1000	.86	.86	.85	.79
ALCOA MA39	900	.85	.47	1.00	.67
ALCOA MA39	1000	.73	.65	.85	.83

TABLE 46

INTERACTIONS OF GREEN DENSITY, HOT COMPACTING PRESSURE AND ALLOY ON QUALITY OF FORGINGS

Alloy	Green Density (%)		Hot Compact Pressure 30 (ksi)	60 (ksi)	90 (ksi)	Average
Percent Metal Recovery						
MA 58	70		88	87	92	89
MA 58	80		66	91	100	86
		AVERAGE	78	89	96	
MA39	70		25	70	93	63
MA39	80		10	78	71	53
		AVERAGE	18	74	82	
		OVERALL AVERAGE	47	81.9	89	
Number of Isolated Discontinuities						
MA 58	70		2	4	3	
MA.58	80		2	0	1	
MA39	70		0	1	0	
MA39	80		0	2	0	

NOTES: (1) Preheated 5 hrs. at 950 F.
(2) Draw forged to 2" square bar.

TABLE 47

INTERACTION OF GREEN DENSITY, HOT COIN PRESSURE AND ALLOY ON LONGITUDINAL PROPERTIES

TENSILE STRENGTH

ALLOY	GREEN DENSITY	HOT COIN PRESSURE 30 KSI	60 KSI	90 KSI
ALCOA MA58	70	74050.	75550.	74300.
ALCOA MA58	80	74050.	75300.	72800.
ALCOA MA39	70	74150.	74050.	73250.
ALCOA MA39	80	71600.	73550.	73100.

YIELD STRENGTH

ALLOY	GREEN DENSITY	HOT COIN PRESSURE 30 KSI	60 KSI	90 KSI
ALCOA MA58	70	66900.	68300.	67650.
ALCOA MA58	80	66750.	67200.	65250.
ALCOA MA39	70	63800.	64500.	62300.
ALCOA MA39	80	61750.	64300.	64300.

ELONGATION

ALLOY	GREEN DENSITY	HOT COIN PRESSURE 30 KSI	60 KSI	90 KSI
ALCOA MA58	70	18.0	18.0	16.0
ALCOA MA58	80	16.0	16.0	19.0
ALCOA MA39	70	16.0	16.0	15.0
ALCOA MA39	80	14.0	16.0	16.0

NOTCH TENSILE STRENGTH - YIELD STRENGTH RATIO

ALLOY	GREEN DENSITY	HOT COIN PRESSURE 30 KSI	60 KSI	90 KSI
ALCOA MA58	70	1.37	1.32	1.31
ALCOA MA58	80	1.36	1.28	1.41
ALCOA MA39	70	1.26	1.25	1.29
ALCOA MA39	80	1.34	1.30	1.29

TABLE 48

INTERACTION OF GREEN DENSITY, HOT COIN
PRESSURE AND ALLOY
ON TRANSVERSE PROPERTIES

TENSILE STRENGTH

ALLOY	GREEN DENSITY	HOT COIN PRESSURE 30 KSI	60 KSI	90 KSI
ALCOA MA58	70	73200.	73450.	72150.
ALCOA MA58	80	69600.	70050.	68550.
ALCOA MA39	70	69200.	71150.	69700.
ALCOA MA39	80	67200.	71300.	70700.

YIELD STRENGTH

ALLOY	GREEN DENSITY	HOT COIN PRESSURE 30 KSI	60 KSI	90 KSI
ALCOA MA58	70	65300.	64400.	64700.
ALCOA MA58	80	60500.	62450.	59350.
ALCOA MA39	70	60650.	61700.	59350.
ALCOA MA39	80	59850.	60950.	61750.

ELONGATION

ALLOY	GREEN DENSITY	HOT COIN PRESSURE 30 KSI	60 KSI	90 KSI
ALCOA MA58	70	11.0	12.0	9.0
ALCOA MA58	80	7.0	6.0	11.0
ALCOA MA39	70	4.0	4.0	7.0
ALCOA MA39	80	5.0	10.0	5.0

NOTCH TENSILE STRENGTH - YIELD STRENGTH RATIO

ALLOY	GREEN DENSITY	HOT COIN PRESSURE 30 KSI	60 KSI	90 KSI
ALCOA MA58	70	.72	.73	.86
ALCOA MA58	80	.83	.83	.84
ALCOA MA39	70	.75	.79	.81
ALCOA MA39	80	.75	.71	.75

TABLE 49

EFFECT OF COLD COMPACTING METHOD ON OUALITY OF 2"x2" HAND FORGINGS

		% Metal Recovery		No. of Discontinuities	
Alloy	Hot Compact Pressure (ksi)	Isostatic Cold Compacting	Uniaxial Cold Compacting	Isostatic Cold Compacting	Uniaxial Cold Compacting
MA58	30	28	88	0	2
MA58	60	92	87	0	4
MA58	90	93	92	5	3
MA39	30	76	25	1	0
MA39	60	89	80	0	1
MA39	90	91	93	1	0
	AVERAGE	78	78	1.1	1.7

NOTES:
(1) Green Density = 70%.
(2) Preheat Time = 5 hours.
(3) Preheat Temp. = 950^{O}F.
(4) Draw Forged to 2"x2".

TABLE 50

EFFECT OF ISOSTATIC AND UNIAXIAL COLD COMPACTING
ON LONGITUDINAL PROPERTIES

TENSILE STRENGTH

	ALCOA MA58			ALCOA MA39		
	HOT COMPACTING PRESSURE					
	30 KSI	60 KSI	90 KSI	30 KSI	60 KSI	90 KSI
UNIAXIAL	74050.	75550.	74300.	74150.	74050.	73250.
ISOSTATIC	73300.	74400.	73900.	75800.	75300.	74900.

YIELD STRENGTH

	ALCOA MA58			ALCOA MA39		
	HOT COMPACTING PRESSURE					
	30 KSI	60 KSI	90 KSI	30 KSI	60 KSI	90 KSI
UNIAXIAL	66900.	68300.	67650.	63800.	64500.	62300.
ISOSTATIC	66850.	68150.	67200.	65450.	64400.	64500.

ELONGATION

	ALCOA MA58			ALCOA MA39		
	HOT COMPACTING PRESSURE					
	30 KSI	60 KSI	90 KSI	30 KSI	60 KSI	90 KSI
UNIAXIAL	18.0	18.0	16.0	16.0	16.0	15.0
ISOSTATIC	16.0	16.0	18.0	15.0	16.0	14.0

NOTCH TENSILE STRENGTH - YIELD STRENGTH RATIO

	ALCOA MA58			ALCOA MA39		
	HOT COMPACTING PRESSURE					
	30 KSI	60 KSI	90 KSI	30 KSI	60 KSI	90 KSI
UNIAXIAL	1.37	1.32	1.31	1.26	1.25	1.29
ISOSTATIC	1.40	1.31	1.42	1.07	1.14	1.21

TABLE 51

EFFECT OF ISOSTATIC AND UNIAXIAL COLD COMPACTING
ON TRANSVERSE PROPERTIES

TENSILE STRENGTH

	ALCOA MA58			ALCOA MA39		
	HOT COMPACTING PRESSURE					
	30 KSI	60 KSI	90 KSI	30 KSI	60 KSI	90 KSI
UNIAXIAL	73200.	73450.	72150.	69200.	71150.	69700.
ISOSTATIC	70850.	75000.	72450.	71300.	72700.	69700.

YIELD STRENGTH

	ALCOA MA58			ALCOA MA39		
	HOT COMPACTING PRESSURE					
	30 KSI	60 KSI	90 KSI	30 KSI	60 KSI	90 KSI
UNIAXIAL	65300.	64400.	64700.	60650.	61700.	59350.
ISOSTATIC	64000.	67850.	64800.	61550.	60450.	59400.

ELONGATION

	ALCOA MA58			ALCOA MA39		
	HOT COMPACTING PRESSURE					
	30 KSI	60 KSI	90 KSI	30 KSI	60 KSI	90 KSI
UNIAXIAL	11.0	12.0	9.0	4.0	4.0	7.0
ISOSTATIC	8.0	7.0	8.0	6.0	6.0	4.0

NOTCH TENSILE STRENGTH - YIELD STRENGTH RATIO

	ALCOA MA58			ALCOA MA39		
	HOT COMPACTING PRESSURE					
	30 KSI	60 KSI	90 KSI	30 KSI	60 KSI	90 KSI
UNIAXIAL	.72	.73	.86	.75	.79	.81
ISOSTATIC	1.00	.89	1.20	.81	.79	.90

TABLE 52

INTERACTIONS OF PREHEAT TIME AND TEMPERATURE
ON QUALITY OF MA58 ALLOY 2" SQUARE HAND FORGINGS
(PROJECT C)

	Preheat Temp. (°F)	Preheat Hours 1	5	20	Average
Percent Metal Recovery					
	900	90	78	91	86
	950	91	92	90	91
	1000	93	94	94	94
	Average	91	88	91	90
Number of Isolated Discontinuities					
	900	5	2	3	
	950	2	3	0	
	1000	4	3	0	

NOTES: (1) Cold Pressed to 70% density.
(2) Not compacted at 90 ksi.

TABLE 53

INTERACTIONS OF PREHEAT TIME, PREHEAT TEMPERATURE ON LONGITUDINAL PROPERTIES OF ALCOA MA58

TENSILE STRENGTH

TEMP. (F)	TIME (HR) 1	5	20
900	75700.	76650.	76100.
950	76600.	74300.	77200.
1000	72900.	76400.	76600.

YIELD STRENGTH

TEMP. (F)	TIME (HR) 1	5	20
900	67450.	68300.	68200.
950	69350.	67650.	69150.
1000	65450.	69200.	69400.

ELONGATION

TEMP. (F)	TIME (HR) 1	5	20
900	14.0	14.0	16.0
950	15.0	16.0	14.0
1000	16.0	16.0	16.0

NOTCH TENSILE STRENGTH - YIELD STRENGTH RATIO

TEMP. (F)	TIME (HR) 1	5	20
900	1.43	1.34	1.23
950	1.35	1.31	1.24
1000	1.45	1.34	1.33

TABLE 54

INTERACTIONS OF PREHEAT TIME, PREHEAT TEMPERATURE ON TRANSVERSE PROPERTIES OF ALCOA MA58

TENSILE STRENGTH

TEMP. (F)	TIME (HR) 1	5	20
900	72750.	70000.	71450.
950	75250.	72150.	70200.
1000	70450.	73400.	74500.

YIELD STRENGTH

TEMP. (F)	TIME (HR) 1	5	20
900	64000.	62300.	63550.
950	65300.	64700.	63250.
1000	61050.	64450.	66400.

ELONGATION

TEMP. (F)	TIME (HR) 1	5	20
900	11.0	6.0	7.0
950	11.0	9.0	6.0
1000	12.0	12.0	8.0

NOTCH TENSILE STRENGTH - YIELD STRENGTH RATIO

TEMP. (F)	TIME (HR) 1	5	20
900	1.09	.65	.60
950	.93	.86	.58
1000	.86	.84	.86

TABLE 55

INTERACTIONS OF PREHEAT TEMPERATURE, HOT COMPACTING PRESSURE AND ALLOY ON QUALITY OF 2" SQ. P/M HAND FORGINGS (PROJECT E)

	Alloy	Preheat Temp. (°F)	Hot Compacting Pressure 30 ksi	60 ksi	90 ksi	Avg.
Percent Metal Recovery						
	MA 58	900	82	87	86	85
	"	950	66	91	100	86
		1000	88	90	95	91
		AVERAGE	78	90	94	
	MA39	900	26	84	66	59
		950	10	78	71	53
		1000	38	68	79	62
		AVERAGE	25	77	72	
		OVERALL AVERAGE	52	83	83	
Number of Isolated Discontinuities						
	MA 58	900	1	6	1	
		950	2	0	1	
		1000	2	6	3	
	MA39	900	0	0	0	
		950	0	2	0	
		1000	0	0	1	

NOTES: (1) Cold pressed to 80% density.
(2) Preheat for 5 hours.

TABLE 56

INTERACTION OF PREHEAT TEMP., HOT COIN PRESSURE AND ALLOY ON LONGITUDINAL PROPERTIES

TENSILE STRENGTH

ALLOY	PREHEAT TEMP.	HOT COIN PRESSURE 30 KSI	60 KSI	90 KSI
ALCOA MA58	900	73650.	75900.	73950.
ALCOA MA58	950	74050.	75300.	72800.
ALCOA MA58	1000	73300.	74950.	73250.
ALCOA MA39	900		74850.	73150.
ALCOA MA39	950	71600.	73550.	73100.
ALCOA MA39	1000	74550.	76000.	74900.

YIELD STRENGTH

ALLOY	PREHEAT TEMP.	HOT COIN PRESSURE 30 KSI	60 KSI	90 KSI
ALCOA MA58	900	66100.	67800.	66550.
ALCOA MA58	950	66750.	67200.	65250.
ALCOA MA58	1000	66100.	68000.	65900.
ALCOA MA39	900		65450.	61350.
ALCOA MA39	950	61750.	64300.	64300.
ALCOA MA39	1000	64950.	67250.	65800.

ELONGATION

ALLOY	PREHEAT TEMP.	HOT COIN PRESSURE 30 KSI	60 KSI	90 KSI
ALCOA MA58	900	19.0	13.0	16.0
ALCOA MA58	950	16.0	16.0	19.0
ALCOA MA58	1000	16.0	18.0	16.0
ALCOA MA39	900		15.0	16.0
ALCOA MA39	950	14.0	16.0	16.0
ALCOA MA39	1000	16.0	16.0	16.0

NOTCH TENSILE STRENGTH - YIELD STRENGTH RATIO

ALLOY	PREHEAT TEMP.	HOT COIN PRESSURE 30 KSI	60 KSI	90 KSI
ALCOA MA58	900	1.31	1.28	1.33
ALCOA MA58	950	1.36	1.28	1.41
ALCOA MA58	1000	1.34	1.38	1.41
ALCOA MA39	900		1.21	1.25
ALCOA MA39	950	1.34	1.30	1.29
ALCOA MA39	1000	1.19	1.25	1.20

TABLE 57

INTERACTION OF PREHEAT TEMP., HOT COIN PRESSURE AND ALLOY ON TRANSVERSE PROPERTIES

TENSILE STRENGTH

ALLOY	PREHEAT TEMP.	HOT COIN PRESSURE 30 KSI	60 KSI	90 KSI
ALCOA MA58	900	73300.	72800.	71100.
ALCOA MA58	950	69600.	70050.	68550.
ALCOA MA58	1000	68900.	72150.	71200.
ALCOA MA39	900		73500.	70200.
ALCOA MA39	950	67200.	71300.	70700.
ALCOA MA39	1000	73450.	73150.	71200.

YIELD STRENGTH

ALLOY	PREHEAT TEMP.	HOT COIN PRESSURE 30 KSI	60 KSI	90 KSI
ALCOA MA58	900	65300.	66050.	63000.
ALCOA MA58	950	60500.	62450.	59350.
ALCOA MA58	1000	60000.	64300.	62750.
ALCOA MA39	900		62950.	59850.
ALCOA MA39	950	59850.	60950.	61750.
ALCOA MA39	1000	63300.	63550.	60950.

ELONGATION

ALLOY	PREHEAT TEMP.	HOT COIN PRESSURE 30 KSI	60 KSI	90 KSI
ALCOA MA58	900	6.0	5.0	8.0
ALCOA MA58	950	7.0	6.0	11.0
ALCOA MA58	1000	7.0	11.0	13.0
ALCOA MA39	900		8.0	7.5
ALCOA MA39	950	5.0	10.0	5.0
ALCOA MA39	1000	12.0	8.0	12.0

NOTCH TENSILE STRENGTH - YIELD STRENGTH RATIO

ALLOY	PREHEAT TEMP.	HOT COIN PRESSURE 30 KSI	60 KSI	90 KSI
ALCOA MA58	900	.72	.81	.64
ALCOA MA58	950	.83	.83	.84
ALCOA MA58	1000	.94	.93	.77
ALCOA MA39	900		.76	.91
ALCOA MA39	950	.75	.71	.75
ALCOA MA39	1000	.75	.81	.86

TABLE 58

EFFECT OF P/M PROCESSING ON MAXIMUM PITTING DEPTH OF ATTACK IN MASTMAASIS TEST

		70% Green Density		80% Green Density		
MA58	1 Hr. Preheat	.0366 .02587	(E3) (a)	.04347 .03375	(E5)	Near Surface T/4
	5 Hr. Preheat	.01912 .02250	(J2)	.03375 .03375	(J4)	Near Surface T/4
MA39	1 Hr. Preheat	.02475 .02025	(E7)	.02025 .01442	(E9)	Near Surface T/4
	5 Hr. Preheat			.04705 .04367	(J6)	Near Surface T/4

NOTES: (a) Forging number.
(b) All "Draw" Forgings (2" square) from uniaxial cold compacts, preheated at 1000°F and hot pressed at 90 ksi.

TABLE 59

EFFECT OF P/M PROCESSING ON MAXIMUM PITTING DEPTH OF ATTACK IN P/M FORGINGS

	Hot Compacting Pressure →	60 ksi		90 ksi		
<u>MA58</u>	1 Hr. Preheat			.04347	(E5)	Near Surface
				.03375		T/4
	5 Hr. Preheat	.02587	(D4) (a)	.03375	(J4)	Near Surface
		.02475		.03375		T/4
<u>MA39</u>	1 Hr. Preheat			.02025	(E9)	Near Surface
				.01442		T/4
	5 Hr. Preheat	.03335	(D8)	.04705	(J6)	Near Surface
		.03937		.04367		T/4

NOTES: (a) Forging number.
(b) All "Draw" Forgings (2" square) from 80% green density uniaxial cold compacts preheated at 1000°F.

TABLE 60

EFFECT OF SECOND STEP AGING TIME ON MA58 FORGING TENSILE AND NOTCHED TENSILE PROPERTIES

Forging No.	Second Step Age (Hrs.@330°F)	Longitudinal T.S. (ksi)	Longitudinal Y.S. (ksi)	Longitudinal El. (% in 4D)	Longitudinal NTS (ksi)	Longitudinal NTS/YS	Transverse T.S. (ksi)	Transverse Y.S. (ksi)	Transverse El. (% in 4D)	Transverse NTS (ksi)	Transverse NTS/YS
379614 E10-1	2	79.6	71.6	16.0	94.6		75.4	67.2	7.5	63.4	
E3-2	4	79.8	72.4	14.0	97.9		76.8	69.3	9.0	57.0	
E3	8	72.9	65.5	16.0	95.0	1.45	70.4	61.1	12.0	52.7	0.86
E11-1	2	80.1	72.3	14.0	96.1		74.8	69.0	4.0	55.5	
E11-2	4	78.2	70.4	14.0	97.1		75.2	67.2	7.0	53.4	
E5	8	77.3	69.5	16.0	94.1	1.35	72.7	63.5	8.0	54.2	0.85
J7-1	2	79.3	71.7	15.0	94.3		75.6	68.9	4.0	54.8	
J7-2	4	79.0	72.2	14.5	95.8		76.8	67.8	9.5	49.6	
J2	8	76.4	69.2	16.0	93.0	1.34	73.4	64.5	12.0	54.0	0.84
J4-1	2	76.9	70.3	16.0	95.3		73.4	64.6	8.5	51.4	
J4	8	73.3	65.9	16.0	92.6	1.41	71.2	62.7	13.0	48.2	0.77
D4-1	2	78.8	71.0	15.0	93.8		76.8	68.8	10.0	46.8	
D4	8	74.9	68.0	18.0	93.9	1.38	72.1	64.3	11.0	59.8	0.93
Average	2		71.2					67.7			
	4		71.7					68.1			
	8		67.6					63.2			

TABLE 61

EFFECT OF SECOND STEP AGING TIME ON MA39 FORGING TENSILE AND NOTCHED TENSILE PROPERTIES

Forging No.	Second Step Age (Hrs.@330°F)	Longitudinal T.S. (ksi)	Longitudinal Y.S. (ksi)	Longitudinal El. (% in 4D)	Longitudinal NTS (ksi)	Longitudinal NTS/YS	Transverse T.S. (ksi)	Transverse Y.S. (ksi)	Transverse El. (% in 4D)	Transverse NTS (ksi)	Transverse NTS/YS
379615 E12-1	2	84.7	78.7	13.0	74.6		83.3	75.5	5.0	39.0	
E12-2	8	79.9	71.4	15.5	83.0		78.7	68.5	6.0	48.8	
E7	16	73.0	63.2	16.0	79.0	1.25	72.1	61.3	10.0	44.7	0.73
E13-1	2	84.[illegible]	81.1	13.0	73.0		84.6	76.4	9.0	35.0	
E9-2	8	79.5	71.3	14.0	83.5		77.6	69.2	4.0	41.9	
E9	16	74.4	65.8	16.0	84.9	1.29	73.4	62.5	8.0	52.9	0.85
J6-1	2	84.6	81.3	13.0	68.8		83.2	76.4	5.5	44.0	
J6	16	74.9	65.8	16.0	78.75	1.20	71.2	60.9	12.0	52.35	0.86
Averages	2		80.4					76.1			
	8		71.4					68.9			
	16		64.9					61.6			

TABLE 62

EFFECT OF ISOSTATIC AND UNIAXIAL COLD COMPACTING ON PROPERTIES OF EXTRUSIONS

		MA58						MA39		
			83% -325 Mesh			29% -325 Mesh			81% -325 Mesh	
	Compacting Method	Sample Number	Longitudinal Properties	Transverse Properties	Sample Number	Longitudinal Properties	Transverse Properties	Sample Number	Longitudinal Properties	Transverse Properties
Tensile Strength	Isostatic	395064-P3	86.7	75.8	395065-S5	91.4	79.7	395066-T3	81.6	76.3
	Uniaxial	395064-P4	86.1	77.8	395065-S4	90.1	79.2	395066-T4	81.9	75.1
Yield Strength	Isostatic		80.2	69.3		85.6	75.0		[illegible]	64.6
	Uniaxial		79.8	70.4		85.2	75.7		[illegible]	65.2
Elongation	Isostatic		12.0	4.0		12.0	2.0		10.0	8.0
	Uniaxial		11.0	6.5		7.0	1.5		11.5	9.0
Notch Tensile Strength-Yield Strength Ratio	Isostatic		1.34	0.59		1.15	0.46		0.97	0.58
	Uniaxial		1.21	0.58		1.13	0.52		1.03	0.61

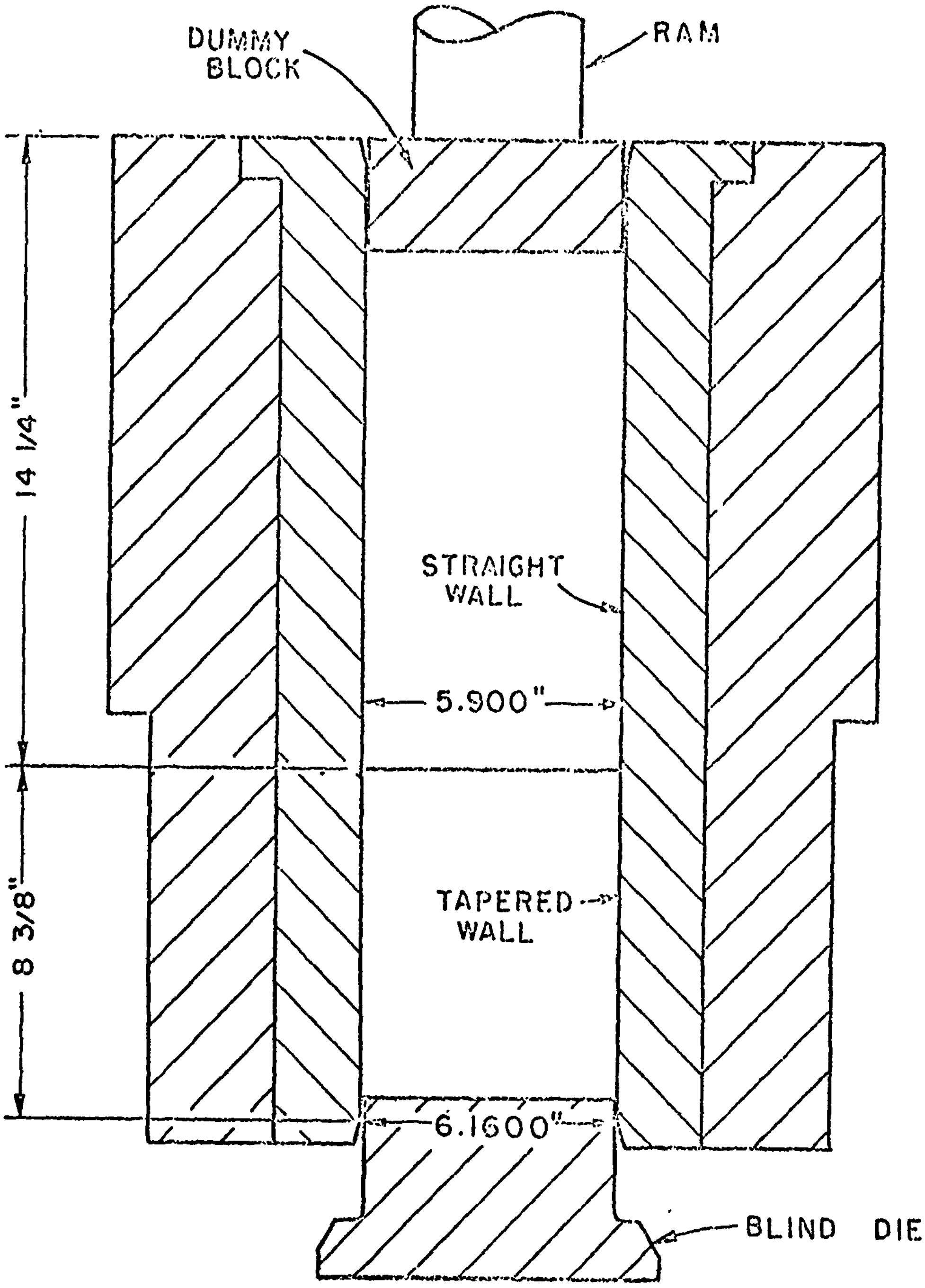
Powder cold compacted to 75% green density, preheated 4.5-5.5 hours at 950°, hot compacted at 90 ksi, and extruded as octagonal rod (12.2:1 extrusion ratio). Solution heat treated 2 hrs. at 890° (MA58) or 2 hrs. at 920° (MA39), CWQ aged 24 hrs. at 250° plus 8 hrs. at 330° (MA58) or 16 hrs. at 330° (MA39). Results are averages of two tests.

TABLE 63

EFFECT OF ISOSTATIC AND UNIAXIAL COLD COMPACTING ON PROPERTIES OF EXTRUSIONS - INDIVIDUAL TEST RESULTS AND STATISTICAL PARAMETERS

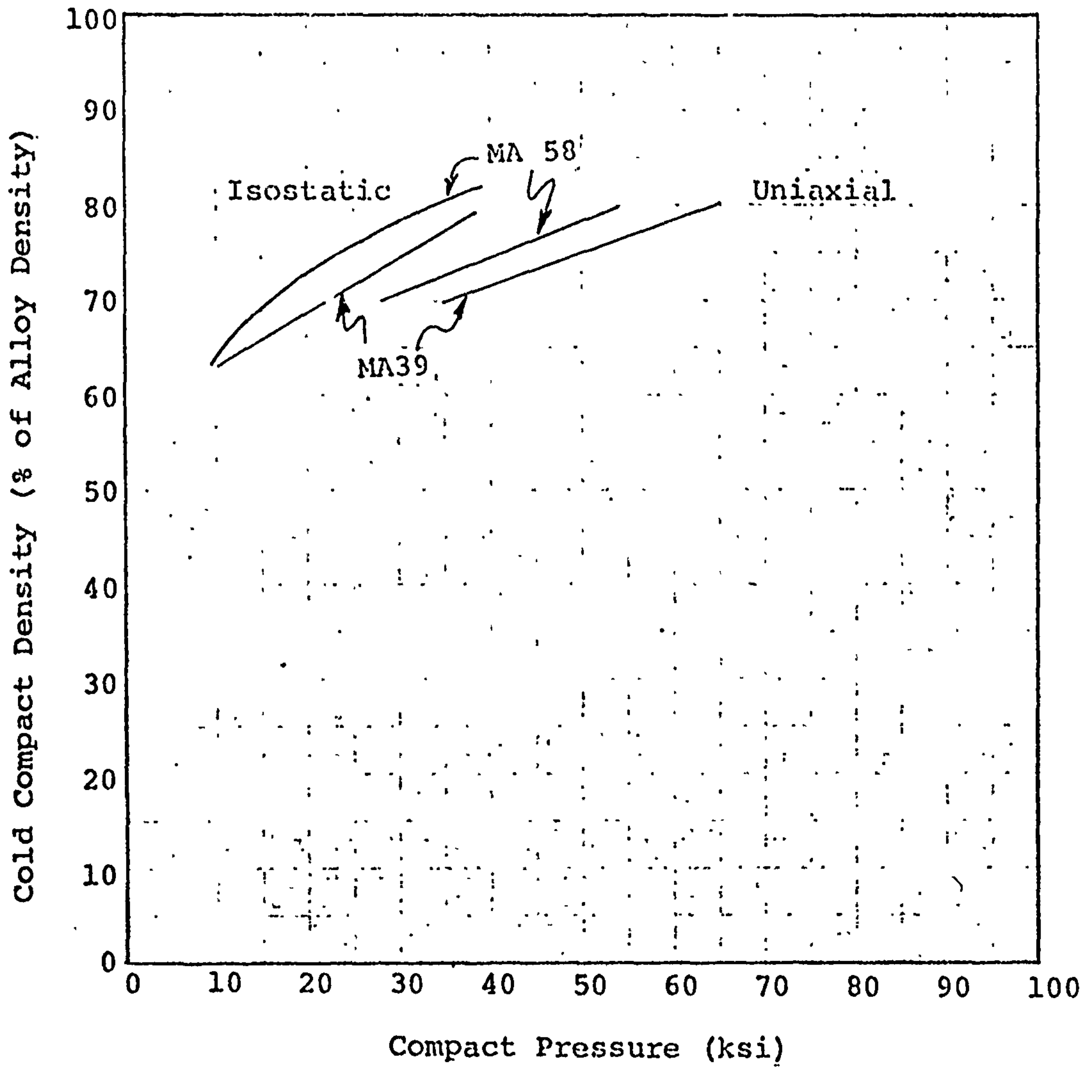
	Longitudinal Direction				Transverse Direction			
	Elongation		NTS/YS		Elongation		NTS/YS	
Alloy-Powder Size	Isostatic	Uniaxial	Isostatic	Uniaxial	Isostatic	Uniaxial	Isostatic	Uniaxial
MA58 Fine	12.0	10.0	1.34	1.21	3.0	6.0	0.53	0.63
	12.0	10.0	1.34	1.21	5.0	7.0	0.64	0.52
MA58 Coarse	12.0	10.0	1.14	1.16	2.0	1.0	0.43	0.56
	12.0	4.0	1.14	1.09	2.0	2.0	0.48	0.46
n	4	4	4	4	4	4	4	4
Average	12.0	9.0	1.24	1.17	3.0	4.0	0.52	0.54
Standard Deviation	0	3.0	0.100	0.005	1.23	2.55	0.078	0.062
Student's t	1.73		2.47		0.61		0.40	
p	<.90		>.95		>.75		>.70	
MA39 Fine	10.0	12.0	0.96	1.00	8.0	4.0	0.59	0.61
	10.0	11.0	0.98	1.05	8.0	9.0	0.56	0.60
n	2	2	2	2	2	2	2	2
Average	10.0	11.5	0.97	1.03	8.0	6.5	0.58	0.61
Standard Deviation	0	0.5	0.010	0.025	0	2.50	0.015	0.005
Student's t	2.12		1.55		0.04		4.24	
p	<.90		<.90		<.55		<.95	

For probabilities of <.95 the difference between test values is not considered significant.



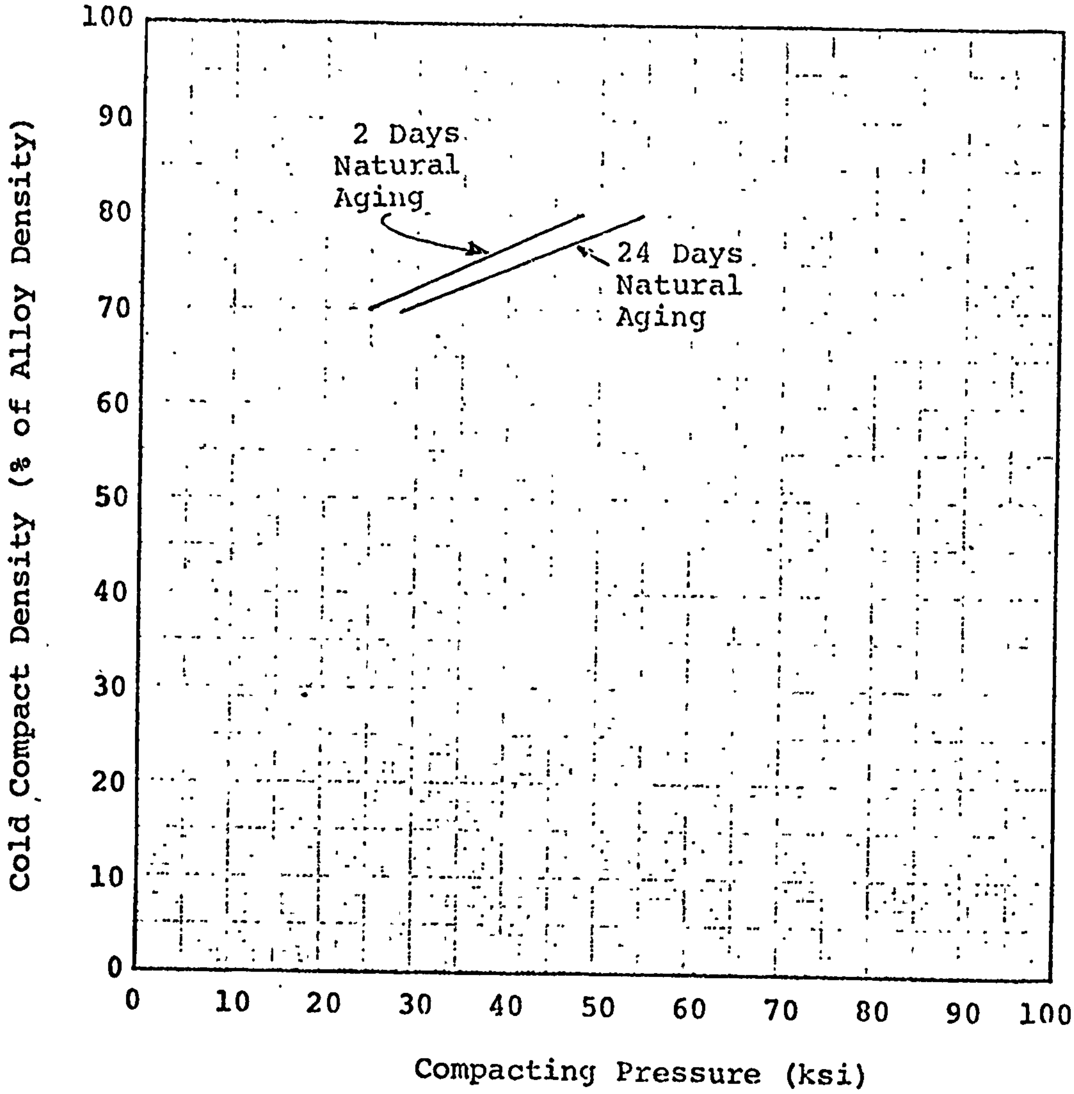
6" Dia. Uniaxial Cold Compacting Die.

Figure 1



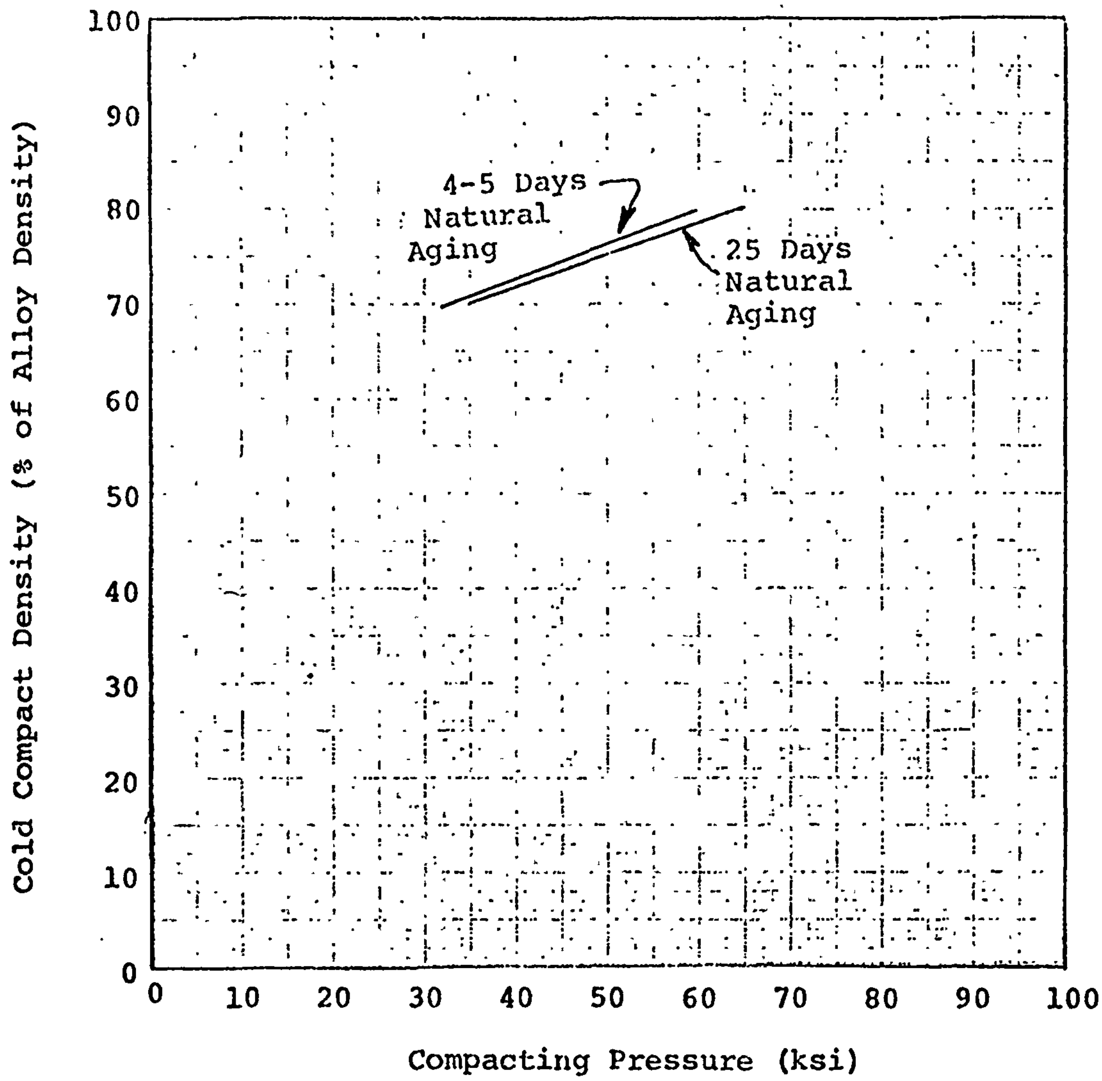
Compacting Pressure vs Cold Compact Density for MA58 (5.9 Zn, 2.2 Mg, 2.1 Cu, 0.1 Zr) and MA39 (8.9 Zn, 3.3 Mg, 0.7 Cu, 0.7 Co) PM Alloys. Comparing Isostatic Pressing to Uniaxial Pressing.

Fig. 2



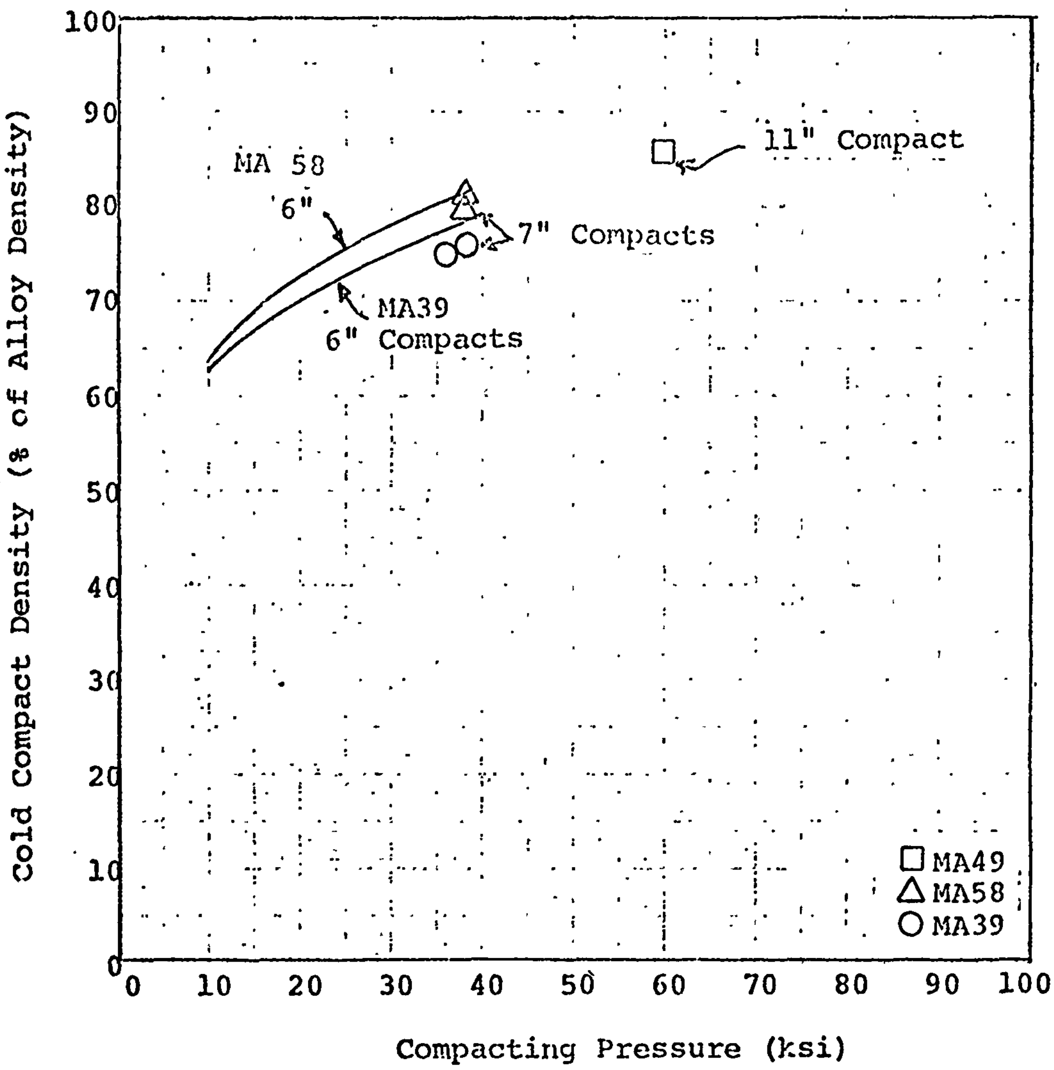
Effect of Natural Aging Time on the Relationship Between Pressure and Density for Uniaxial Compacting of MA58.

Fig. 3



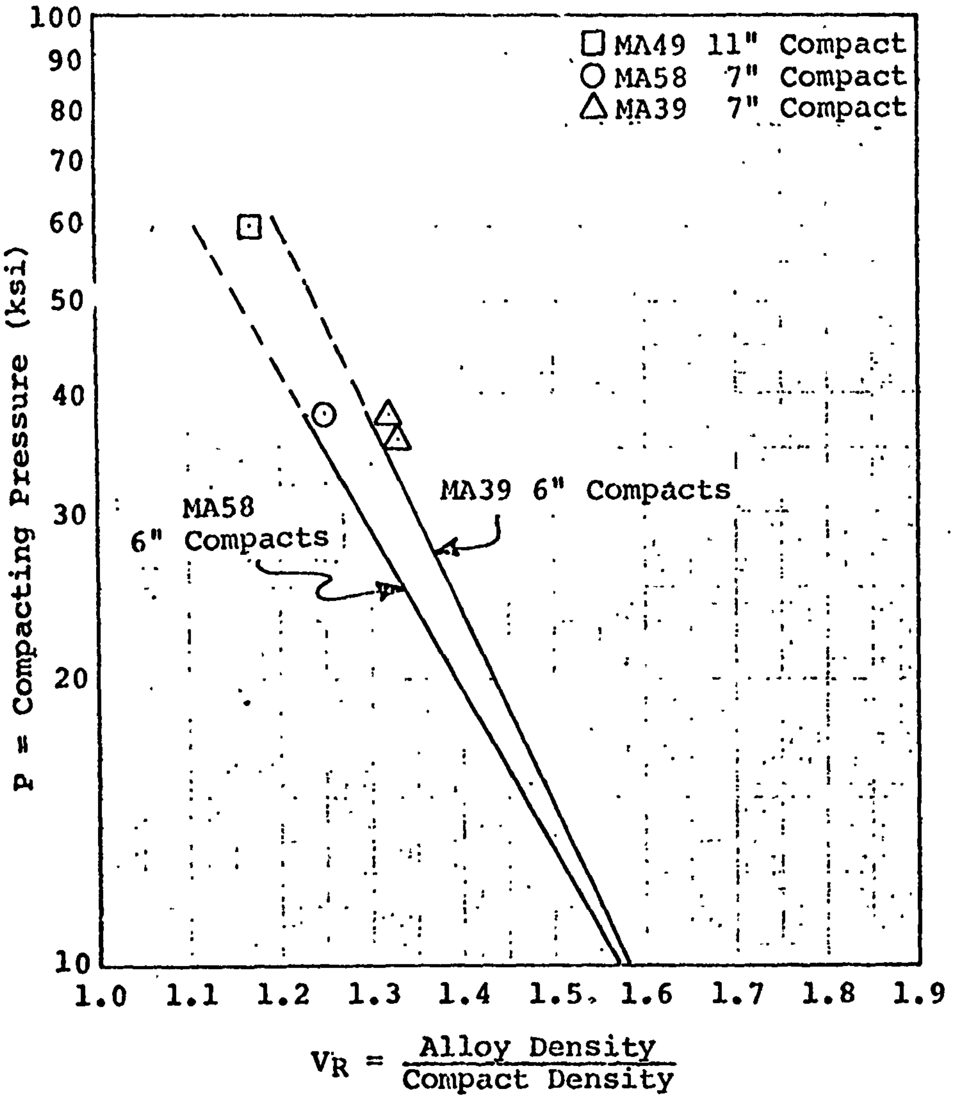
Effect of Natural Aging Time on the Relationship Between Pressure and Density for Uniaxial Compacting of MA39.

Fig. 4



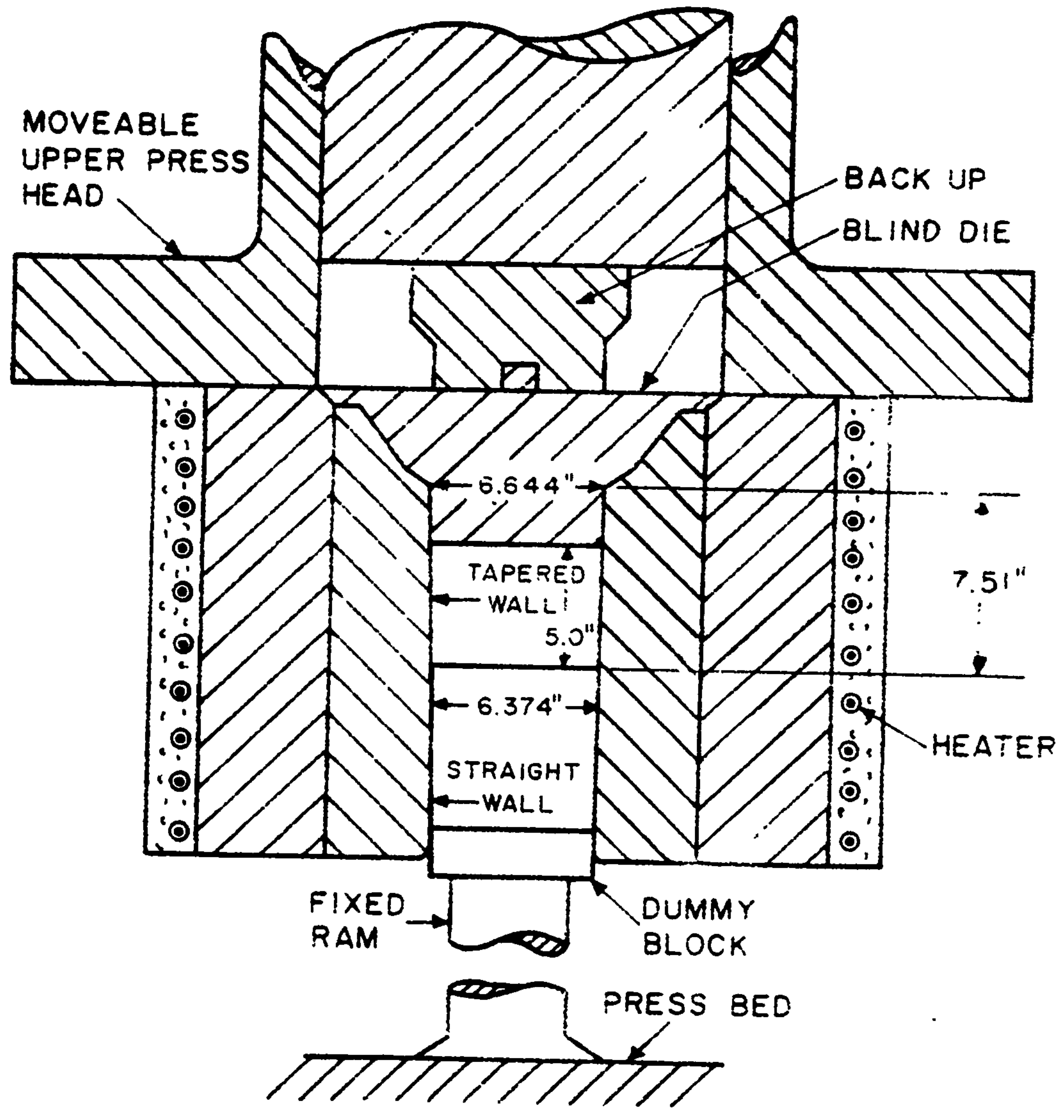
Effect of Compact Size on Pressure Versus Density Relationship for MA58 and MA39 Alloys for Isostatic Cold Compacting.

Fig. 5



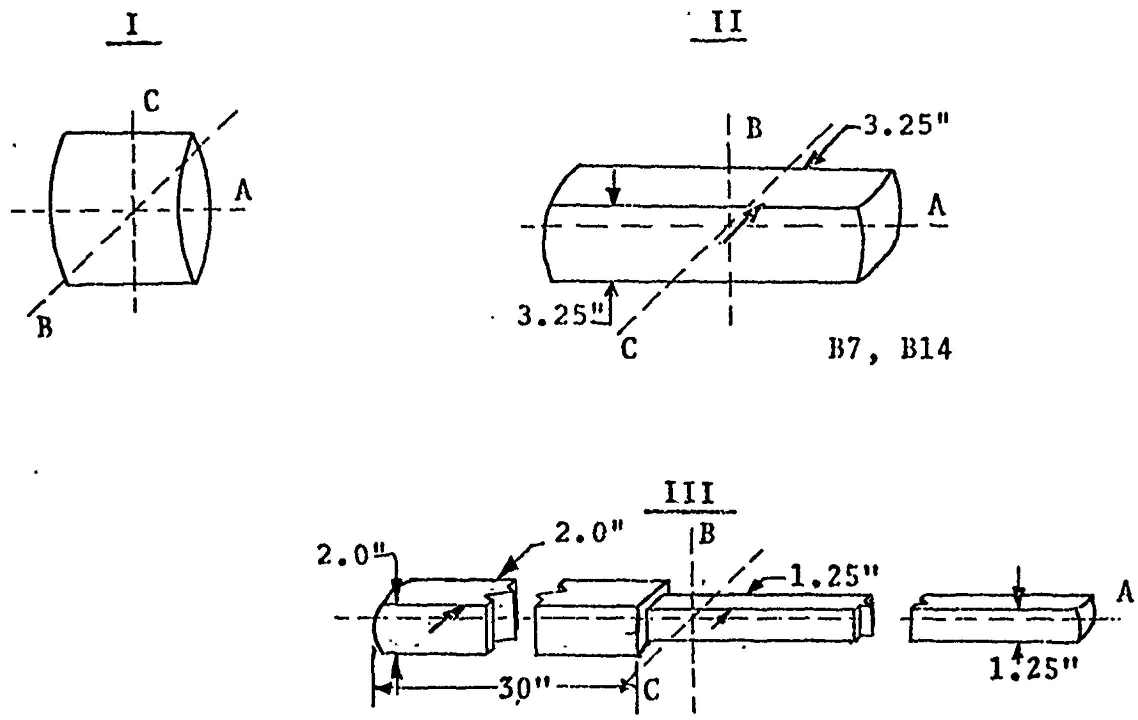
Compact Density as a Function of
Compacting Pressure
(Log Pressure = AV_R + Constant)

Figure 6



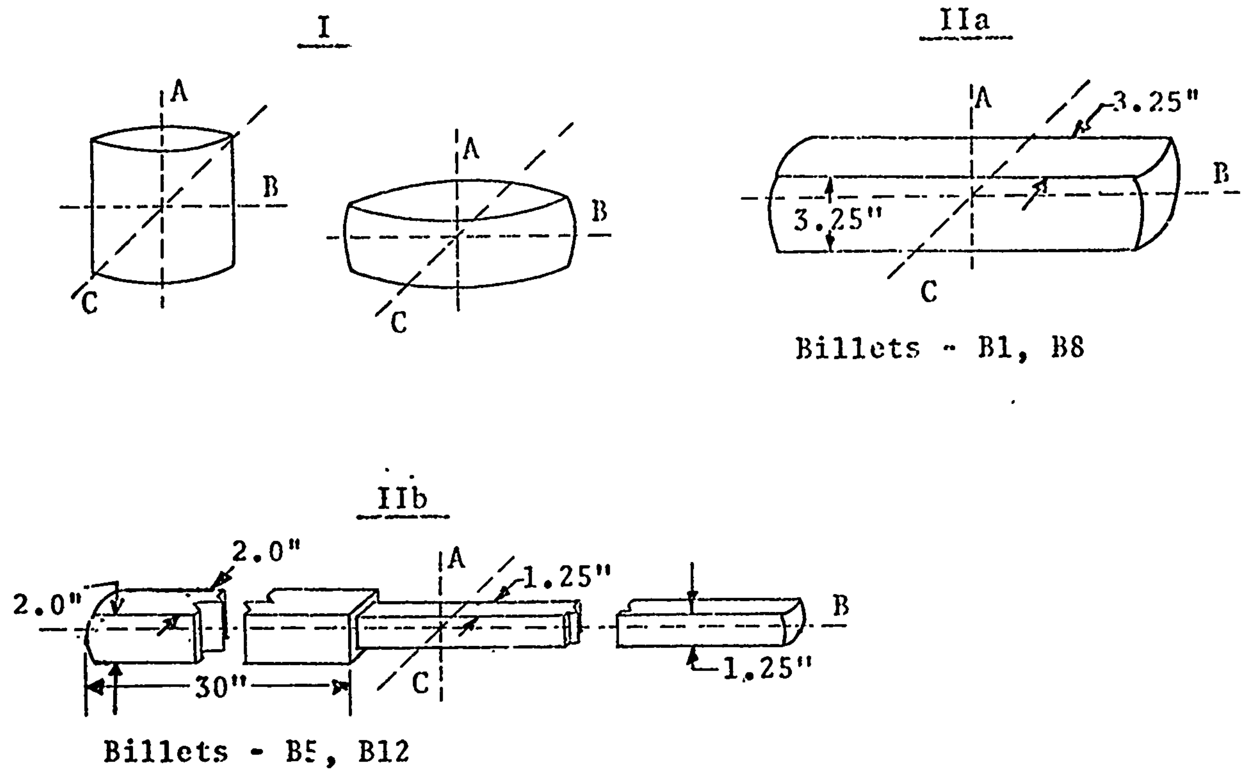
SCHEMATIC OF 6.4" DIAMETER HOT COMPACTING CYLINDER

FIGURE 7



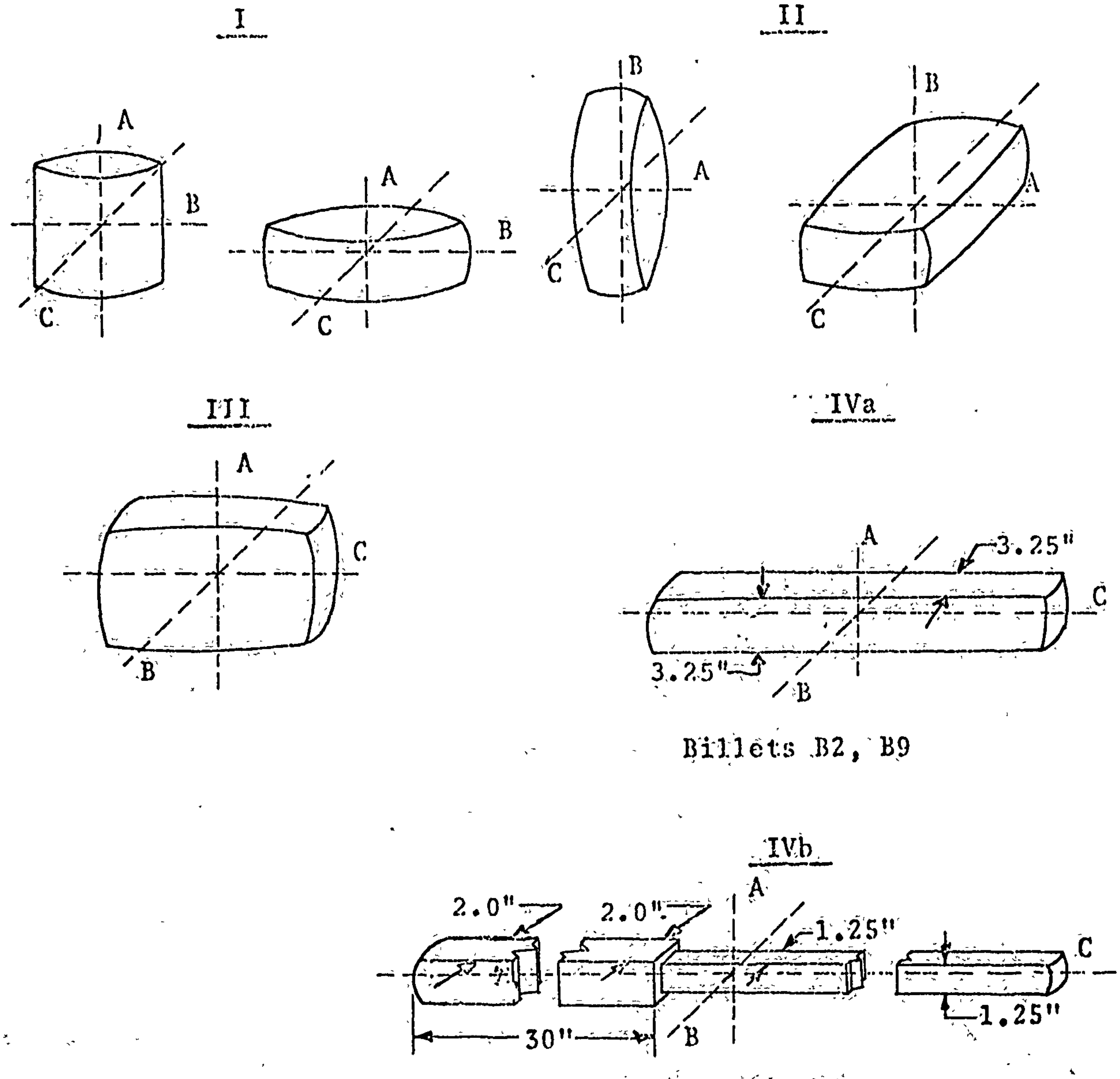
Draw Forging Operation for Billets - B4, B11.

Figure 8



A-Upset and Draw Forging Operation for the Compacts Shown.

Figure 9

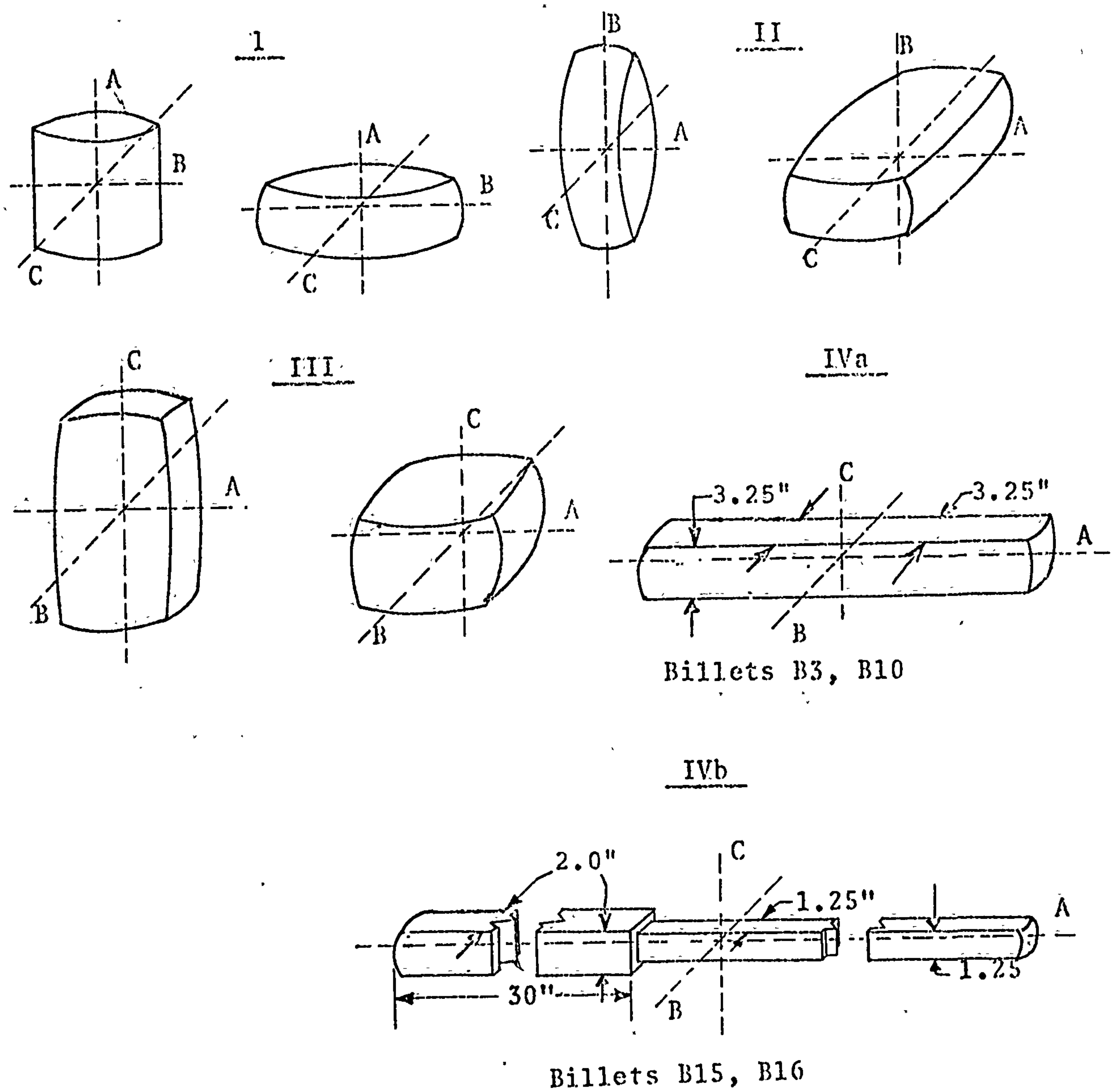


Billets B2, B9

Billets B6, B13

A-B Upset and Draw Forging Sequence for the Compacts Shown.

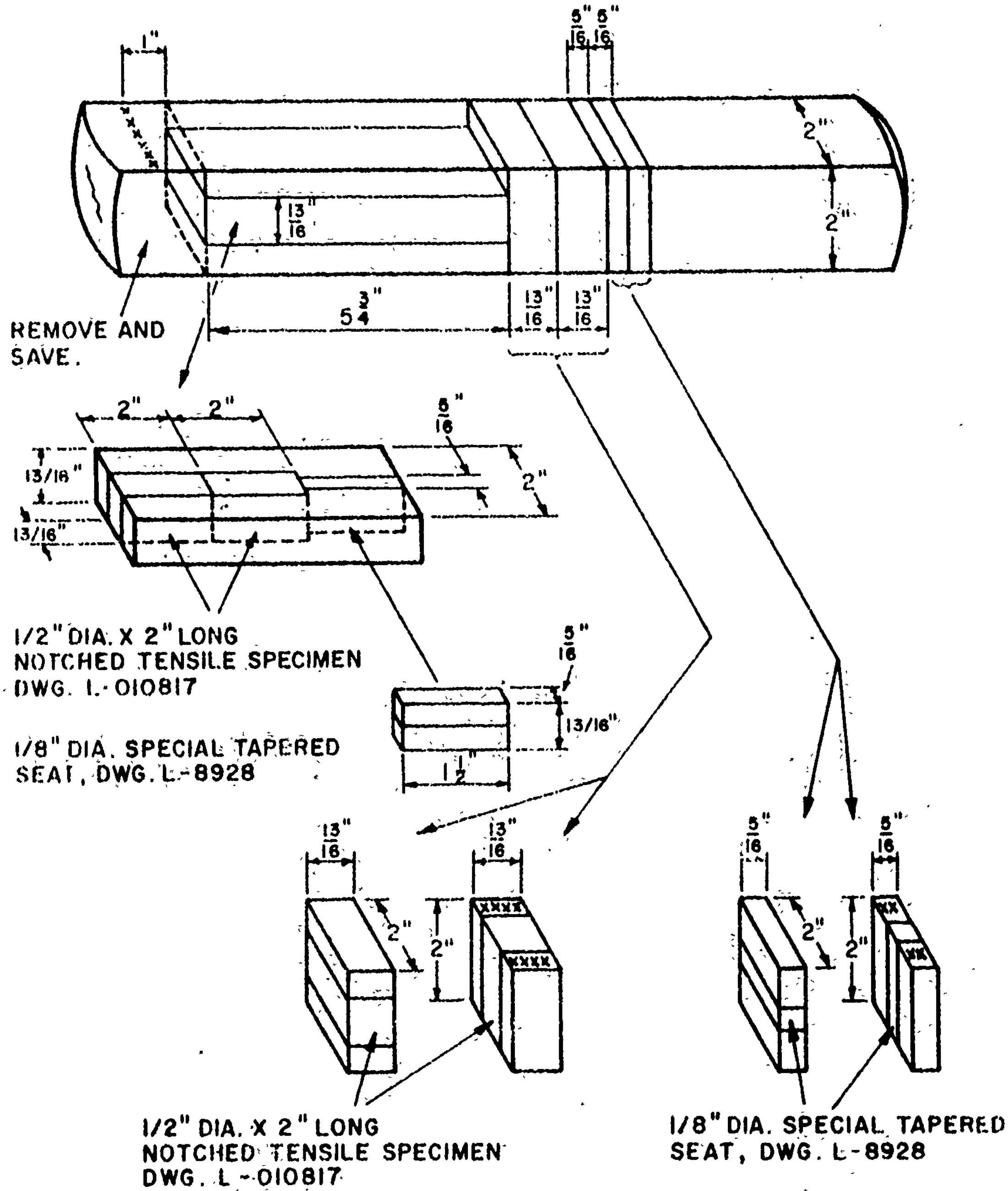
Figure 10



A-B-C Upset and Draw Forging Sequence for the Compacts Shown.

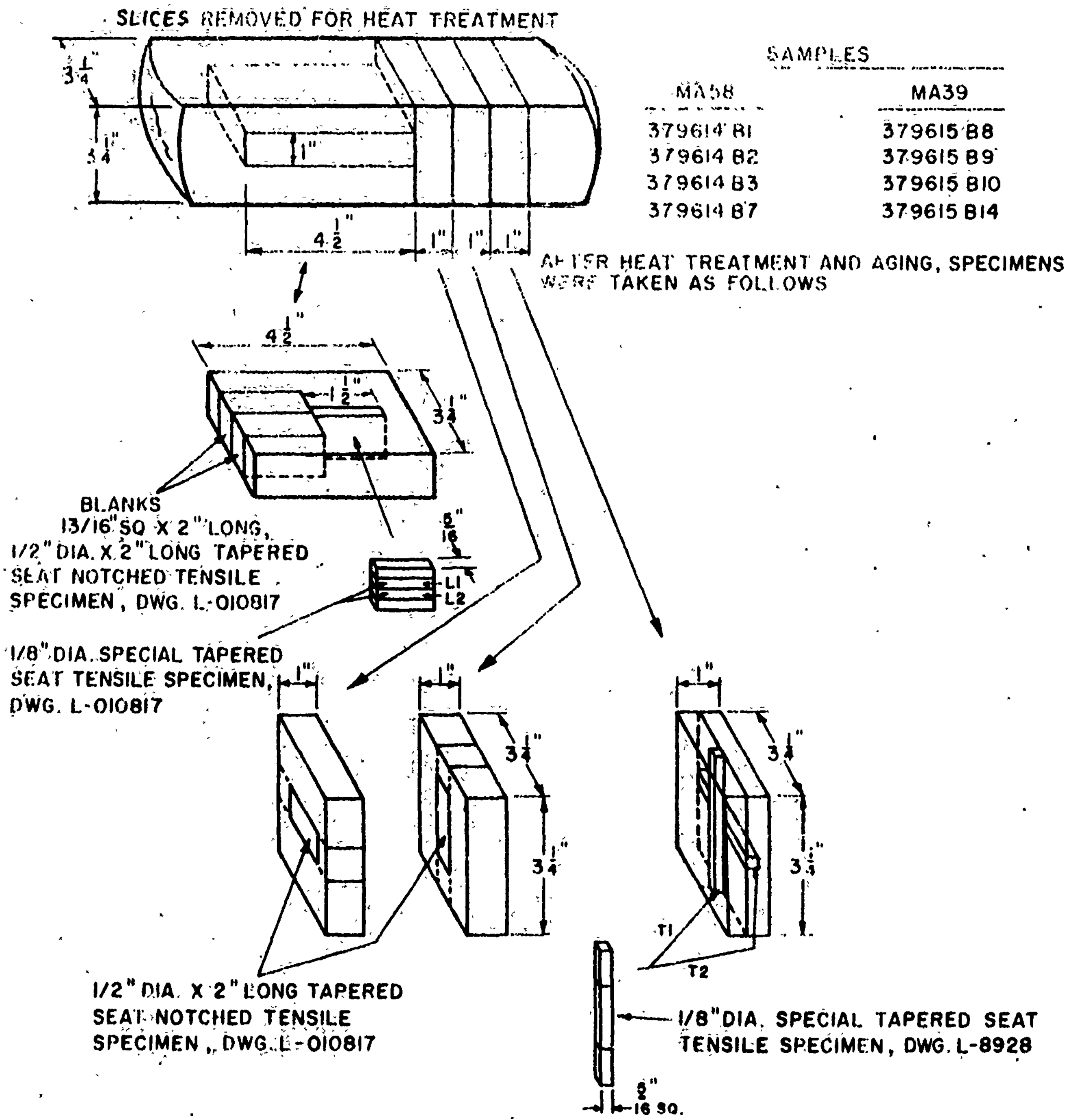
Figure 11

FORGINGS HEAT TREATED AS 2" SQUARE BAR. SAMPLED AFTER AGING AS FOLLOWS



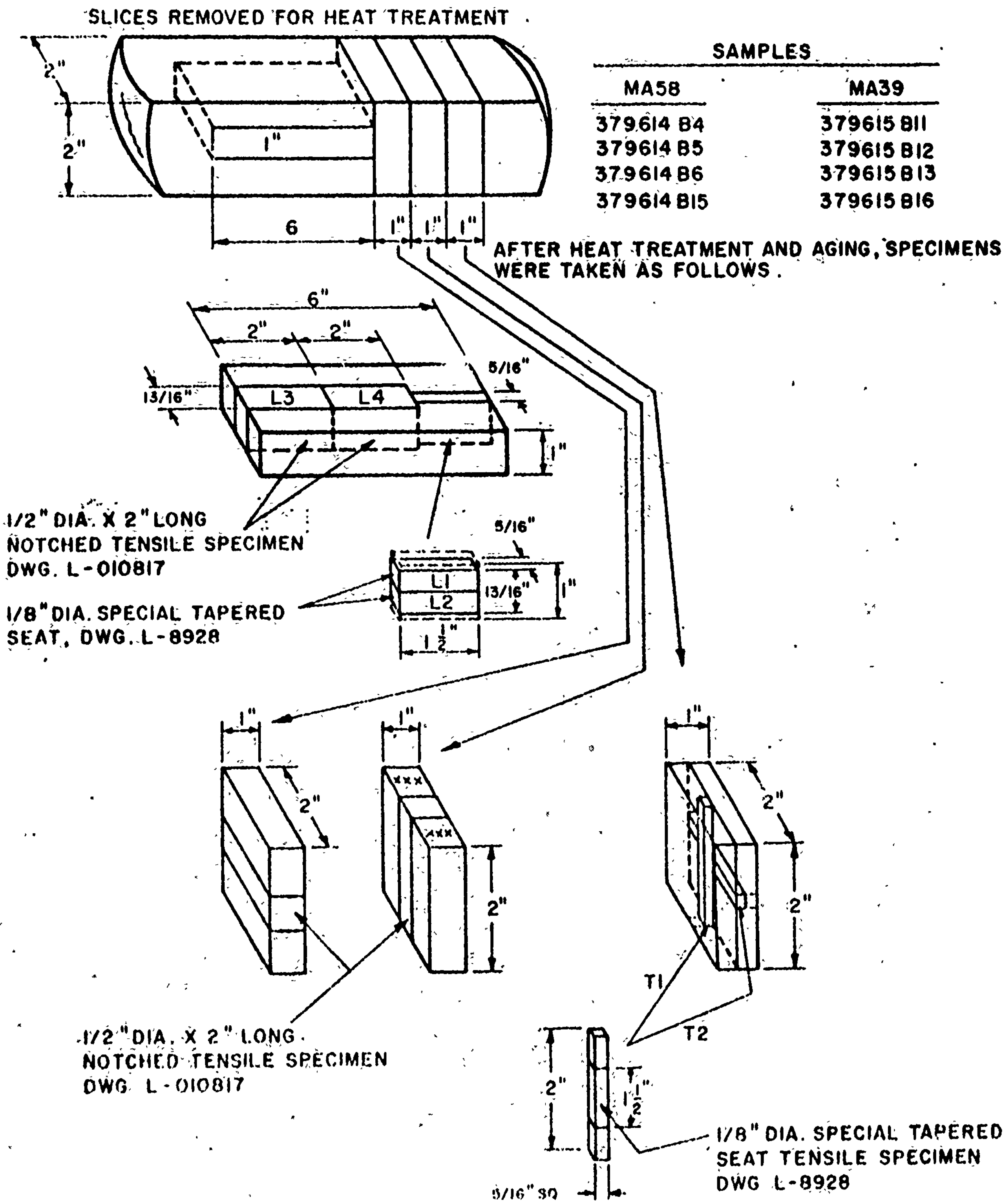
SAMPLING OF 2" SQUARE FORGED BAR

FIG.12



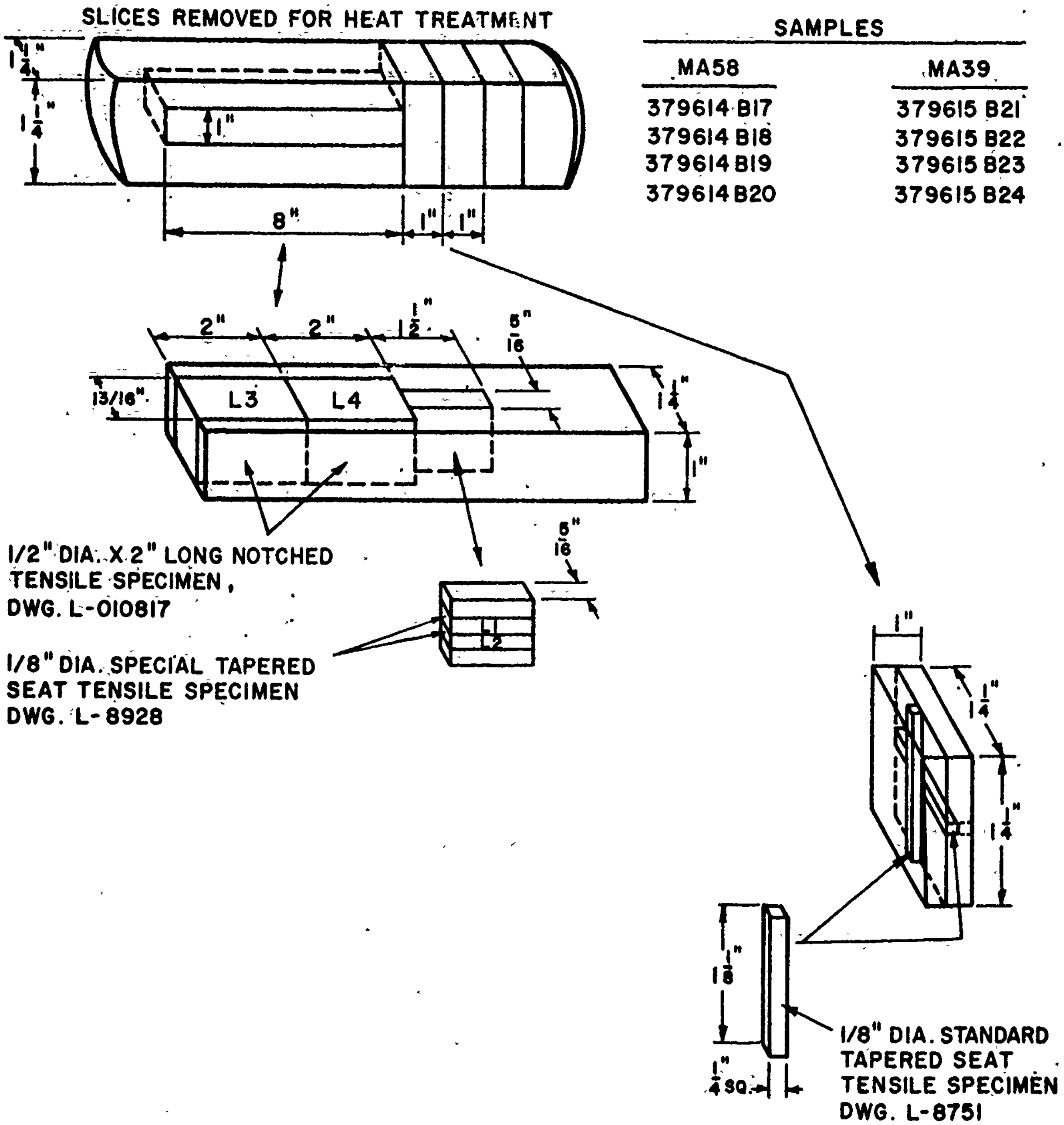
SAMPLING OF 3.25" SQUARE FORGED BAR

FIG.13



SAMPLING OF 2" SQUARE FORGED BAR

FIG. 14

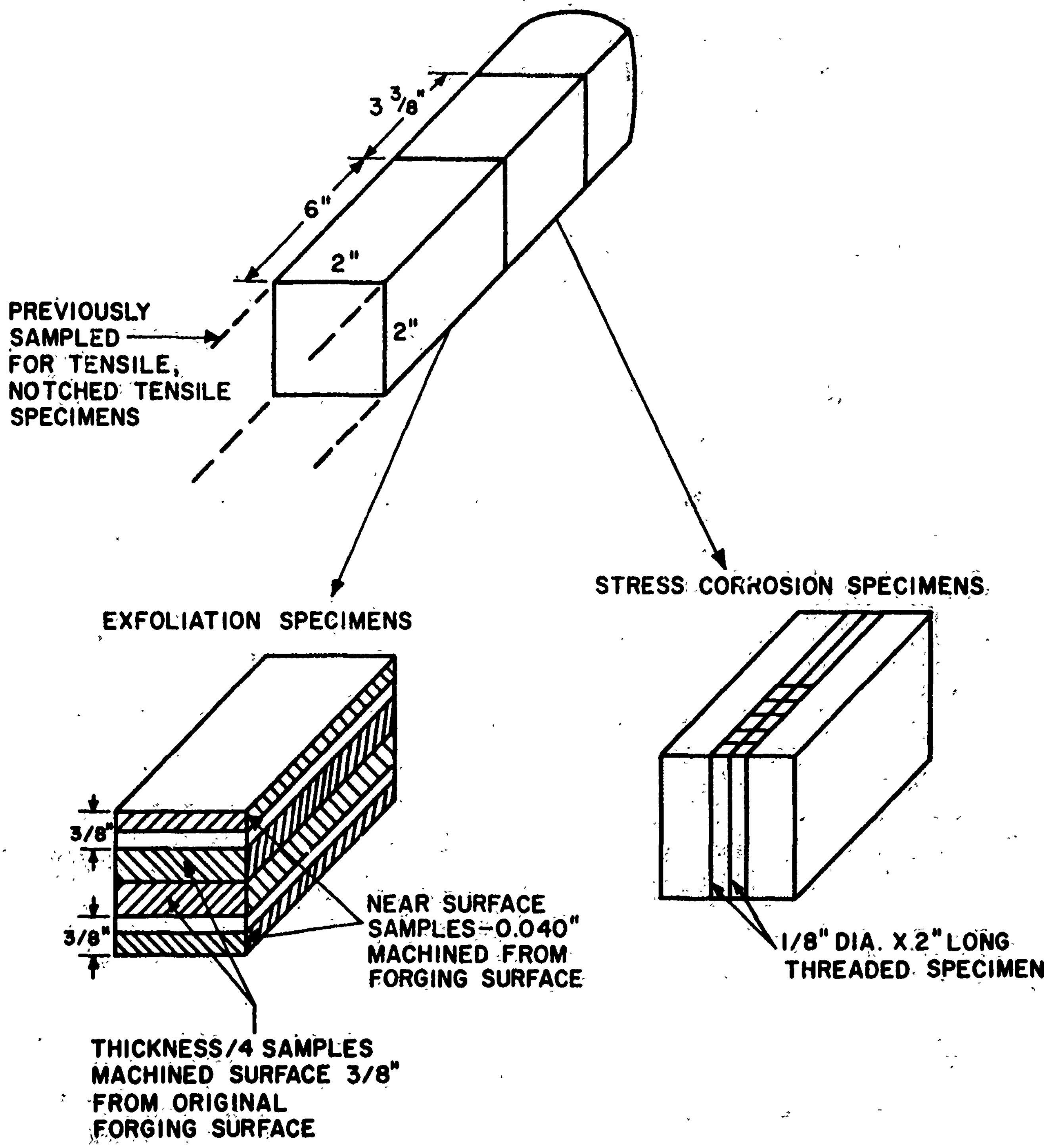


SAMPLES

MA58	MA39
379614 B17	379615 B21
379614 B18	379615 B22
379614 B19	379615 B23
379614 B20	379615 B24

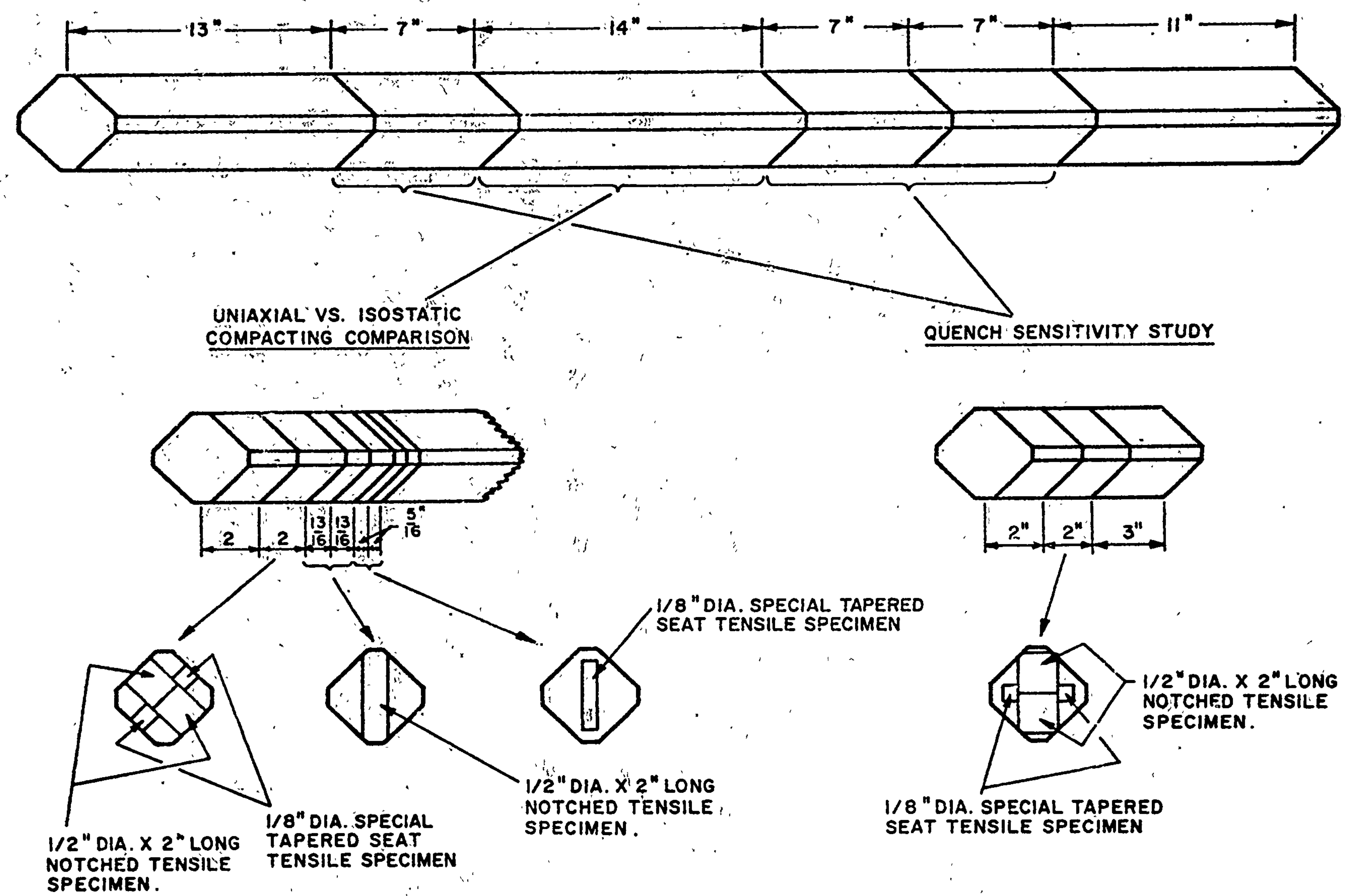
SAMPLING OF 1.25" SQUARE FORGED BAR

FIG. 15



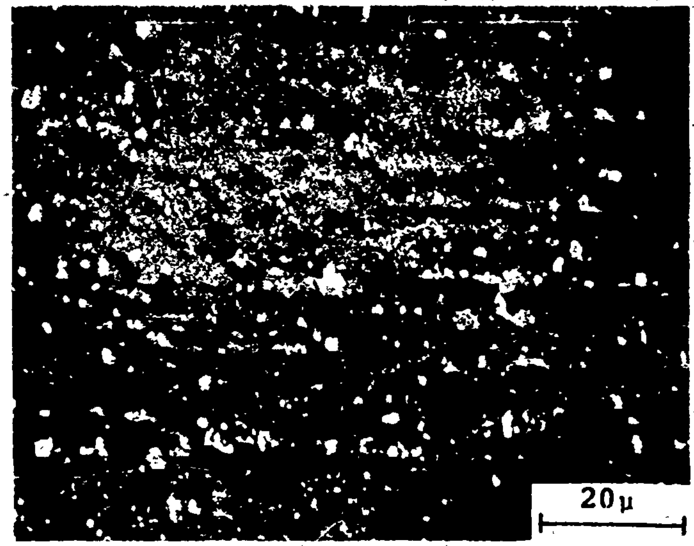
SAMPLE LAYOUT FOR EXFOLIATION AND STRESS CORROSION SPECIMENS FROM 2" SQ. HAND FORGINGS

FIG.16

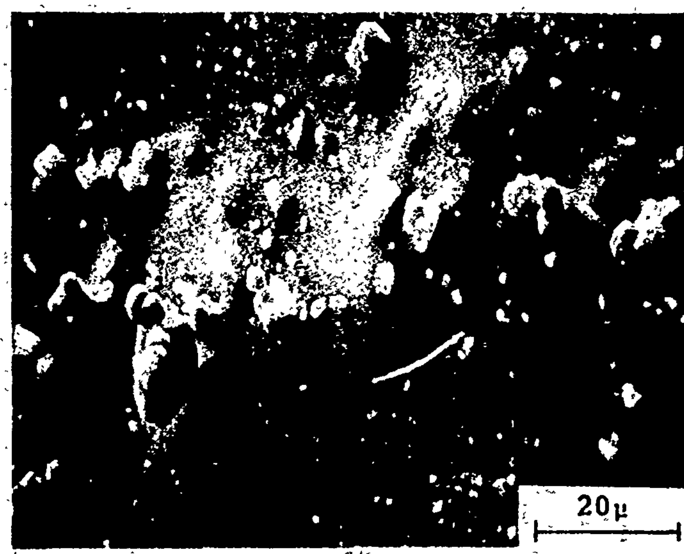


SAMPLING LAYOUT OF OCTAGONAL EXTRUDED ROD

FIG.17

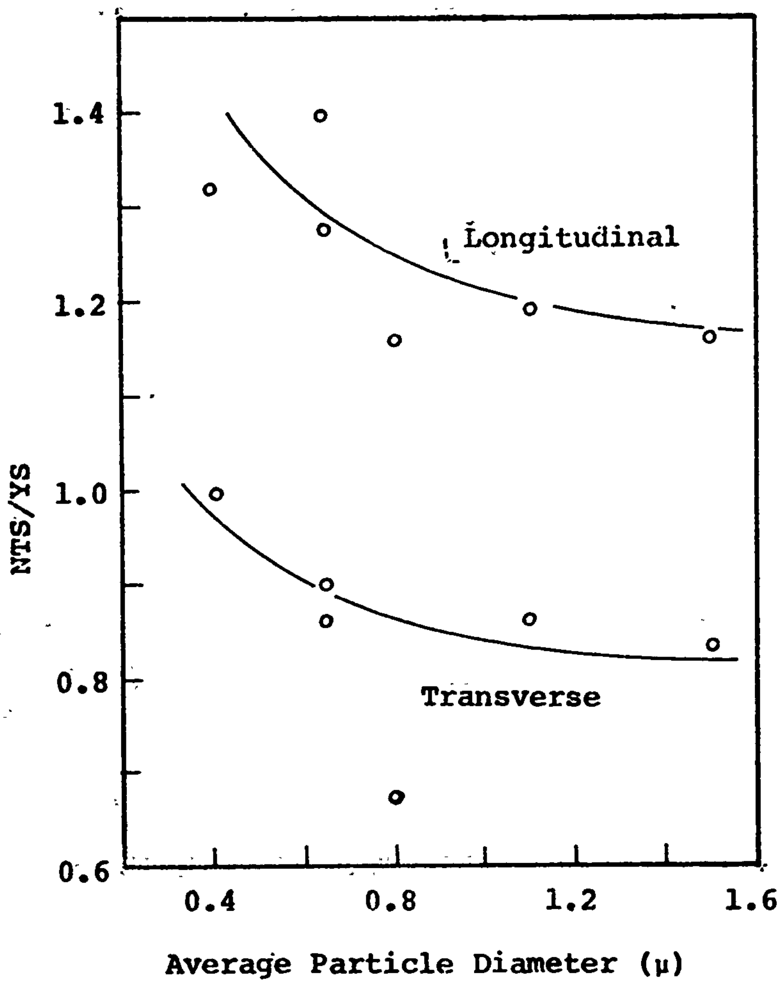


MA39 Forging, Preheated 1 hr at 1000 F
(1000X, Bromine in Methanol Etch)



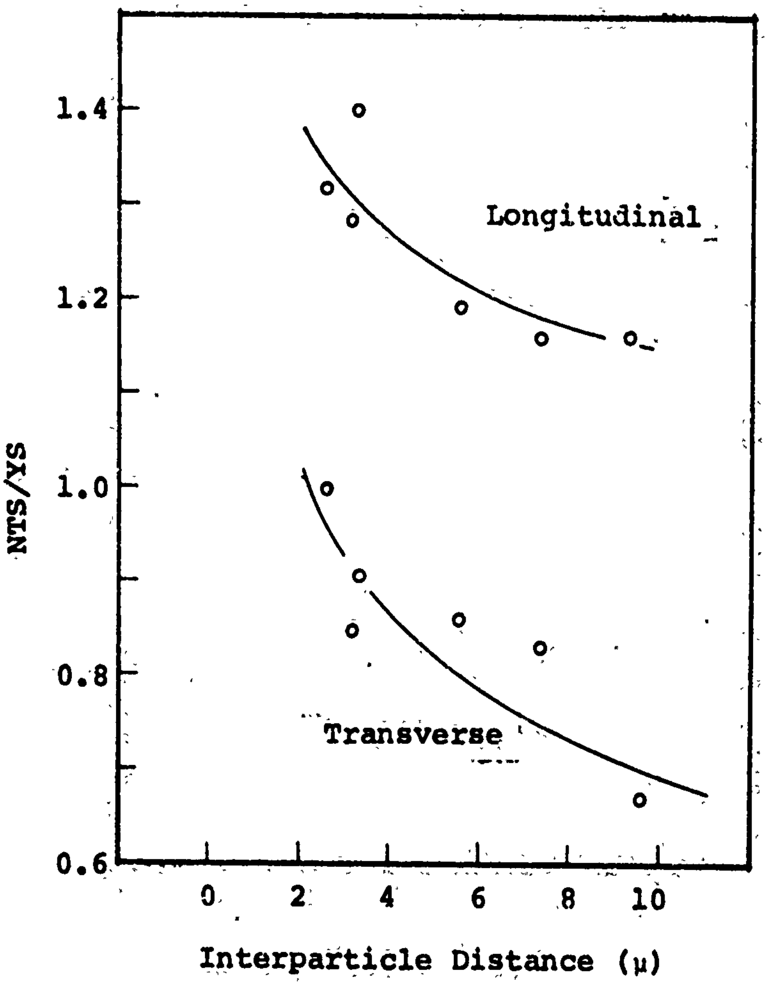
MA39 Forging, Preheated 20 hr at 1000 F
(1000X, Bromine in Methanol Etch)

Figure 18



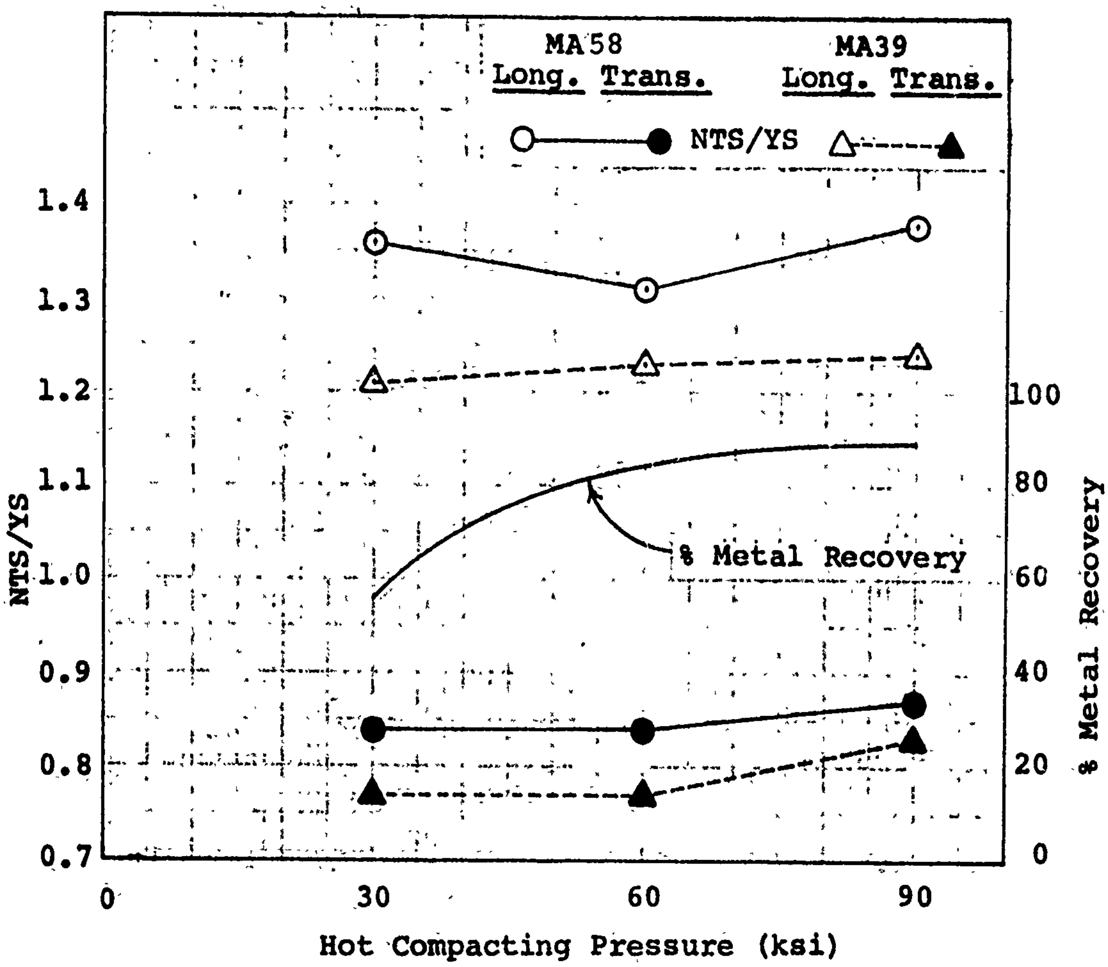
Relation of Longitudinal and Transverse NTS/YS to Co_2Al_9 Particle Size in MA39 Forgings

Figure 19



Relation of Longitudinal and Transverse NTS/YS to Interparticle Spacing of Co_2Al_9 Constituent in MA39 Forgings.

Figure 20



Effect of Hot Compacting Pressure on %
Metal Recovery and Notched Tensile Strength:
Yield Strength Ratio (NTS/YS)

Figure 21

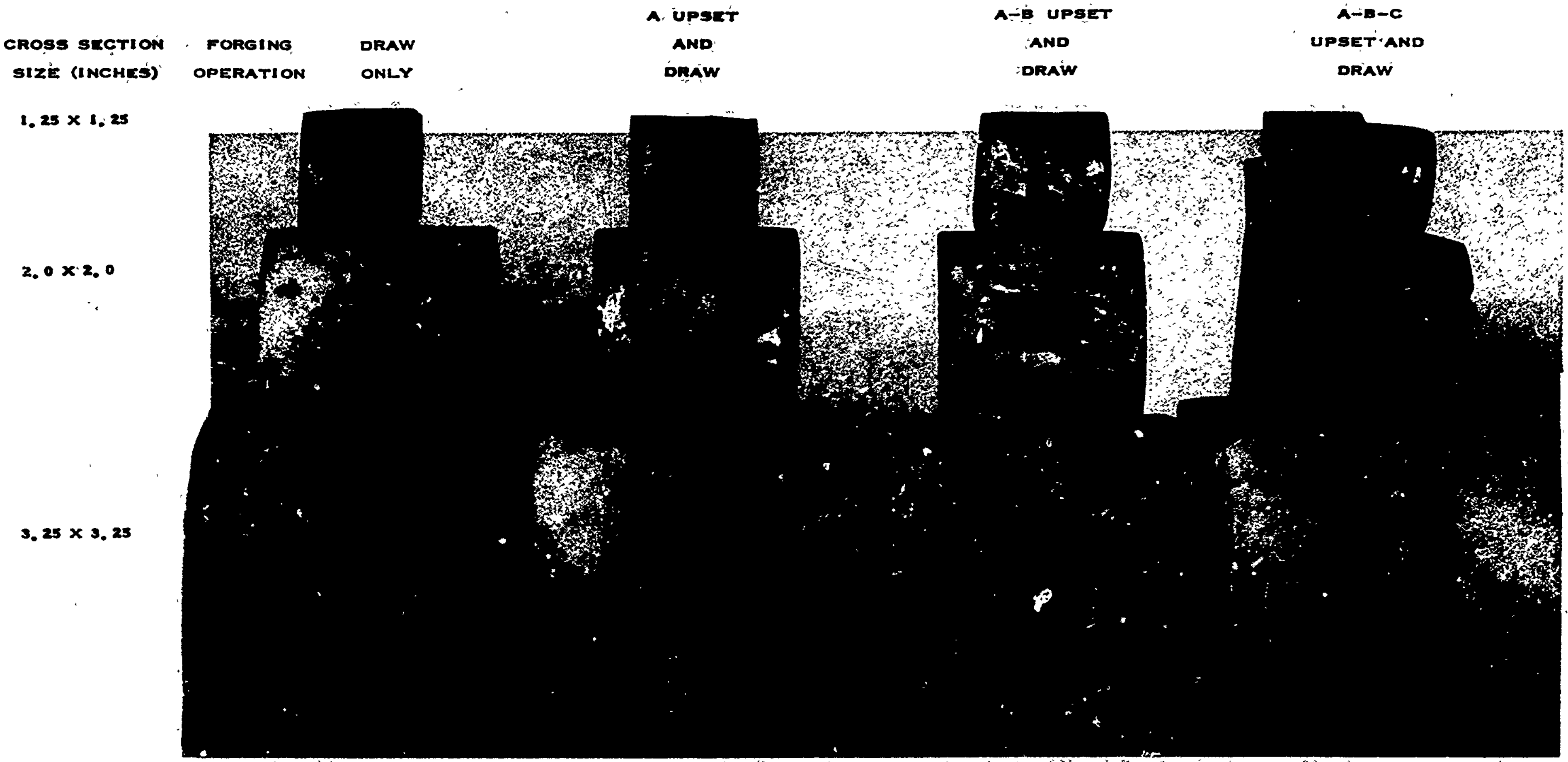


FIGURE 22 EFFECT OF TYPE AND AMOUNT OF DEFORMATION ON END CRACKING FOR MA58 ALLOY HAND FORGINGS. THE END CRACKS SHOWN EXTEND ONLY 0.5 TO 1.8 INCHES INTO THE FORGING.

CROSS SECTION SIZE (INCHES) | FORGING OPERATION | DRAW ONLY | A UPSET AND DRAW | A-B UPSET AND DRAW | A-B-C UPSET AND DRAW

1.25 X 1.25

2.0 X 2.0

3.25 X 3.25

FIGURE 23 EFFECT OF TYPE AND AMOUNT OF DEFORMATION ON END CRACKING FOR MA39 ALLOY HAND FORGINGS. THE END CRACKING SHOWN EXTENDS ONLY FROM 0.5 TO 2.0 INCHES INTO THE FORGING.

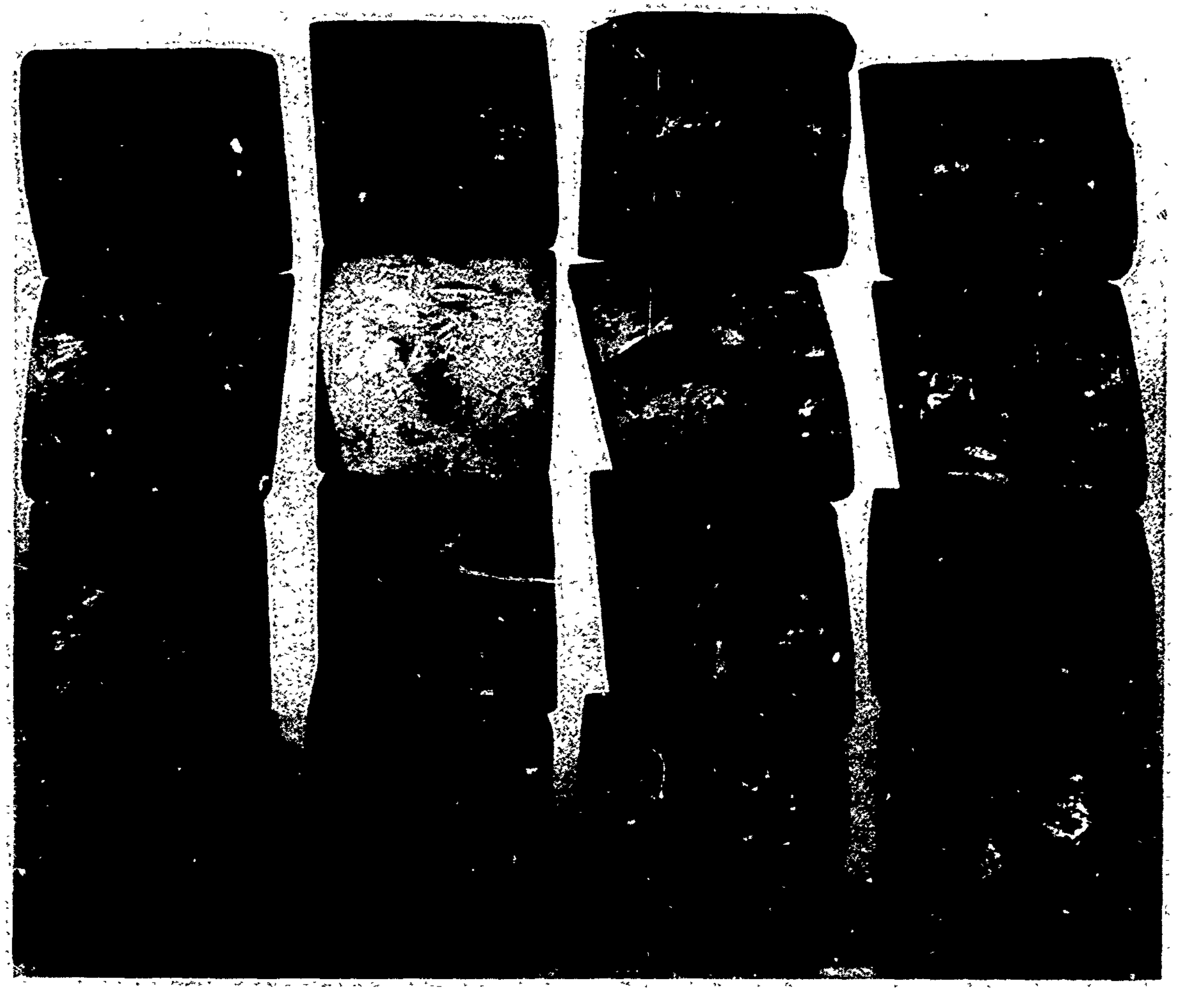
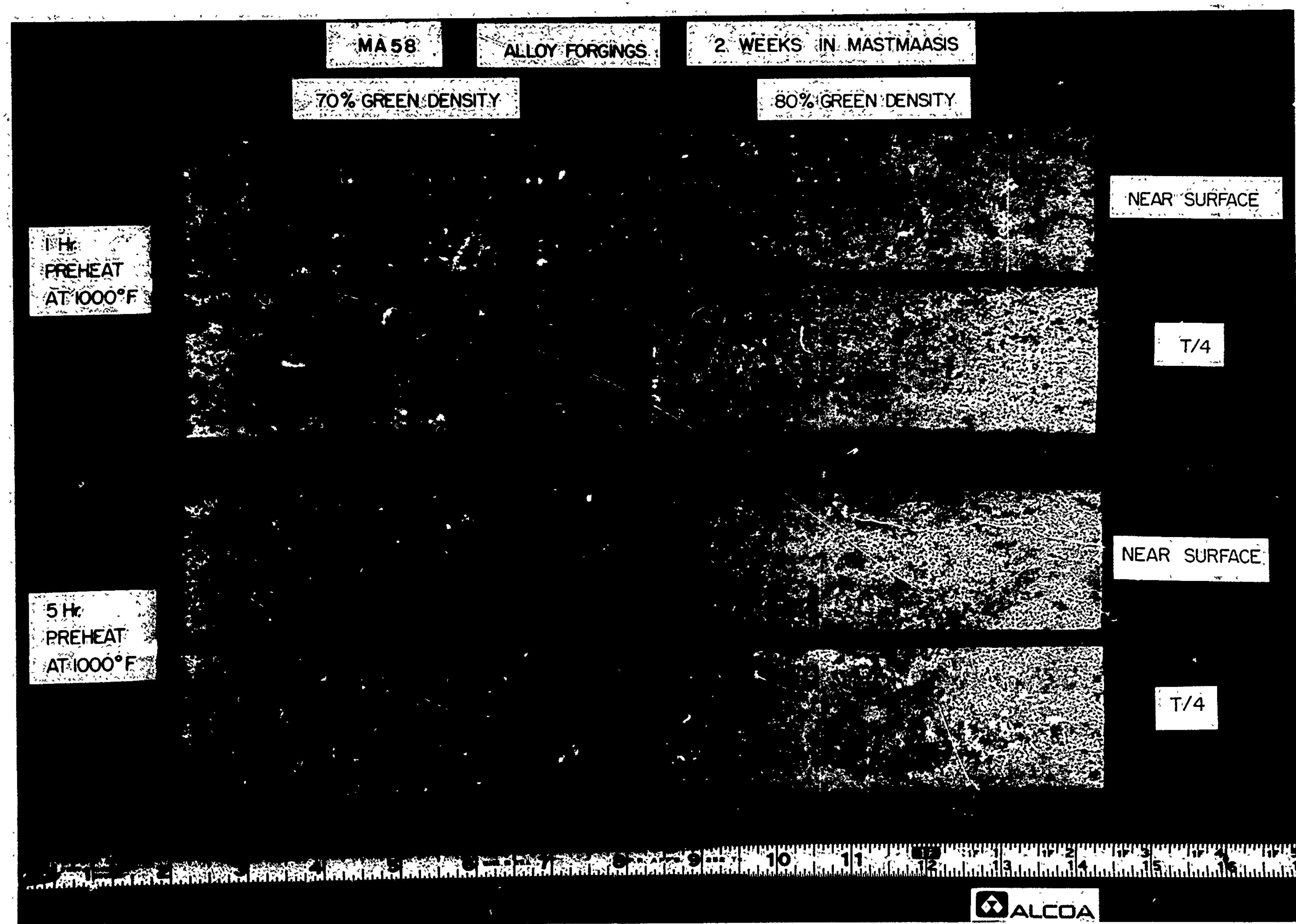
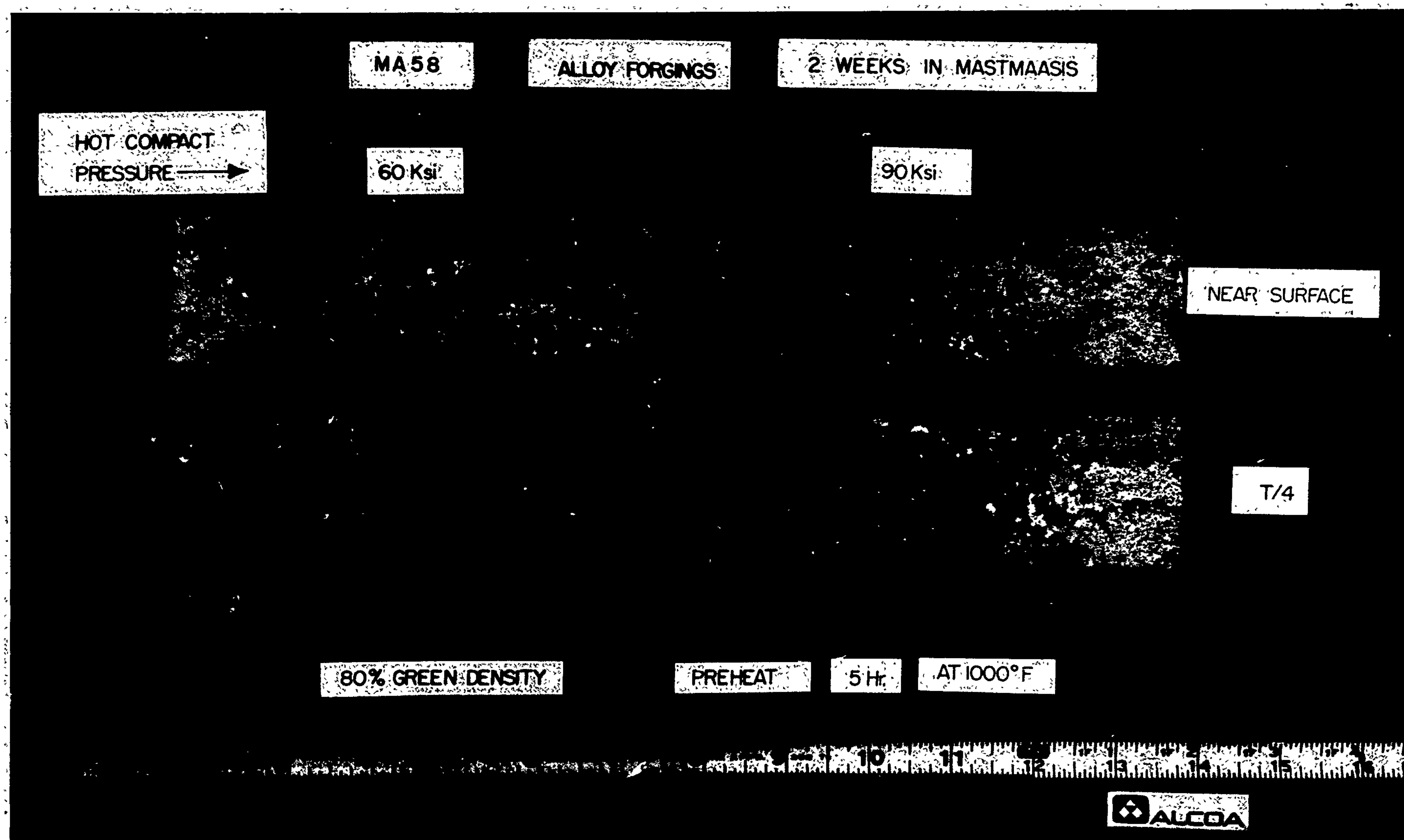


FIGURE 24 INT RACTIONS OF GREEN DENSITY, PREHEAT TIME, PREHEAT TEMPERATURE AND ALLOY ON END CRACKING OF 2 X 2 HAND FORGINGS. THE END CRACKING SHOWN EXTENDS ONLY FROM 1 TO 2.5 INCHES INTO THE MA15 FORGINGS AND FROM 2 TO 4 INCHES INTO THE MA39 FORGINGS.



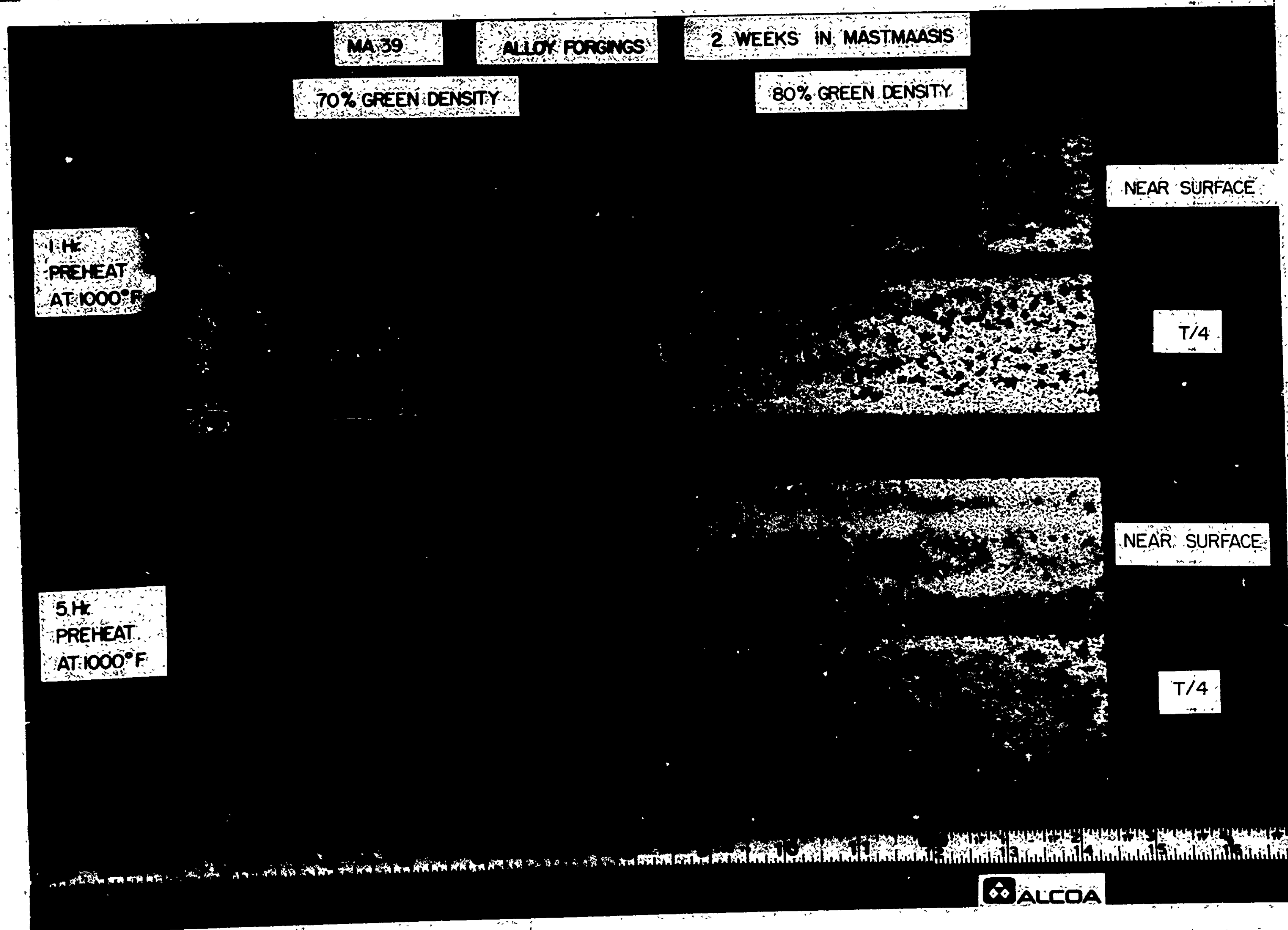
Effect of Green Density, Preheat Time and Sample Location on Exfoliation Corrosion of 2" Square Forgings

Figure 25



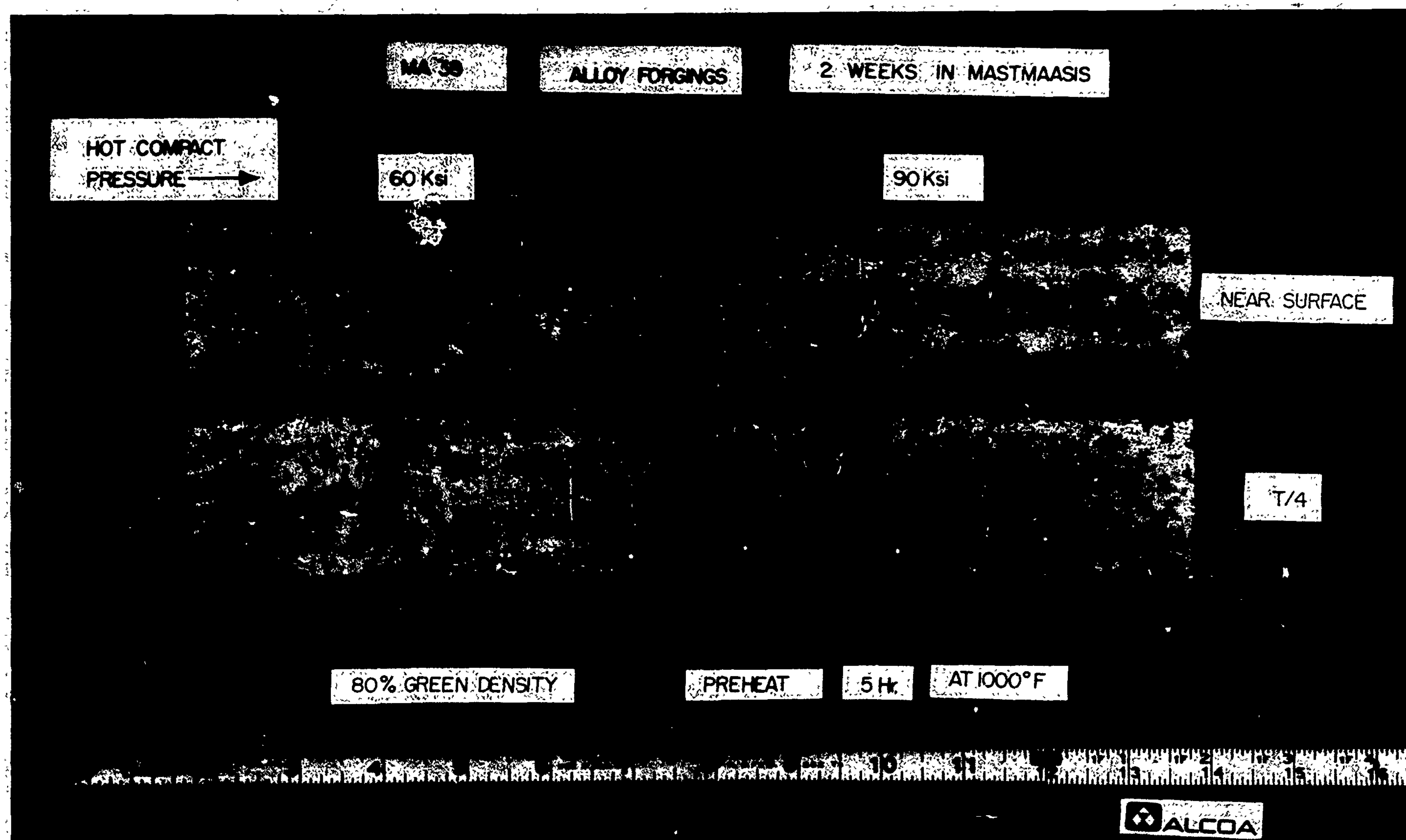
Effect of Hot Compact Pressure and Sample Location on Exfoliation Corrosion of 2" Square Forgings

Figure 26



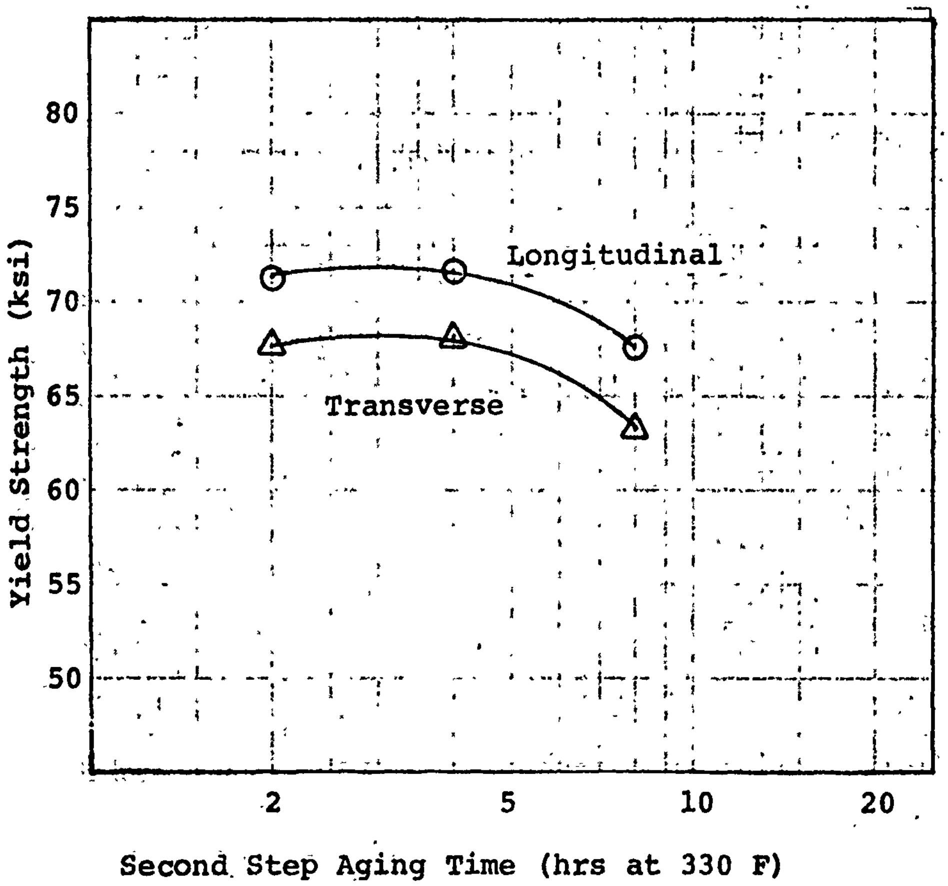
Effect of Green Density, Preheat Time and Sample Location on Exfoliation Corrosion of 2" Square Forgings

Figure 27



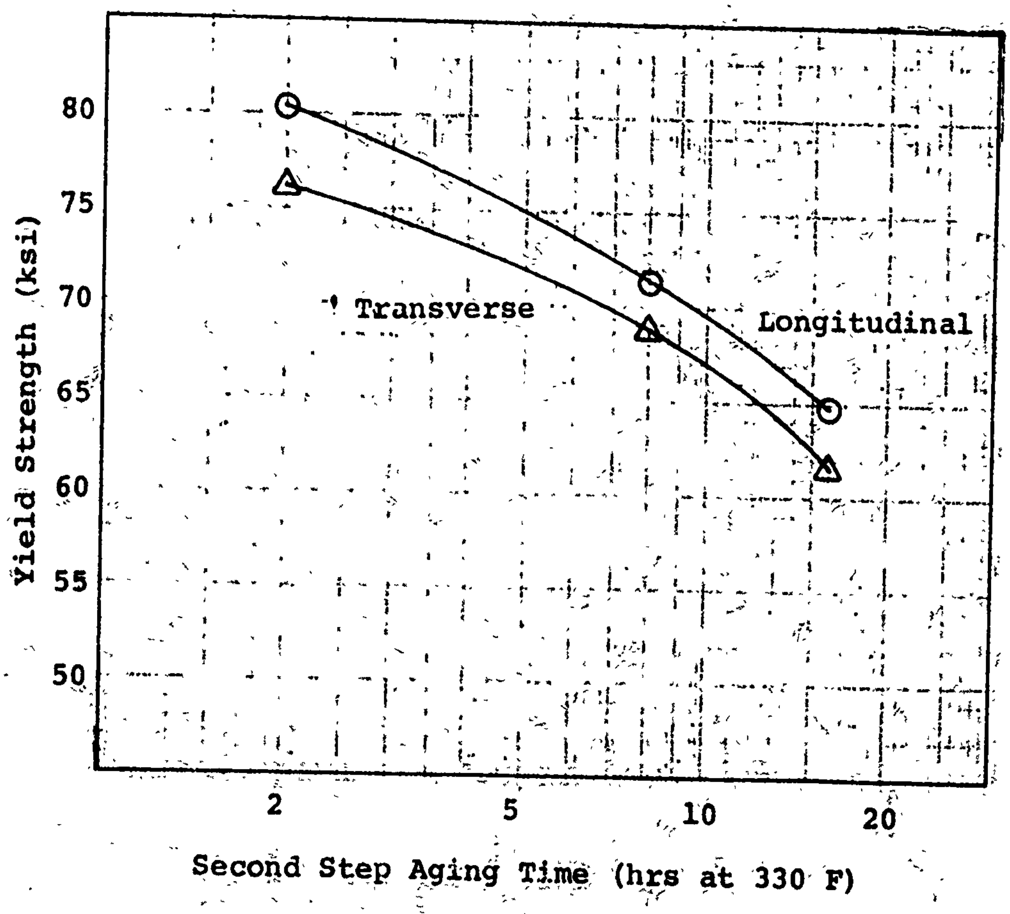
Effect of Hot Compact Pressure and Sample Location on Exfoliation Corrosion of 2" Square Forgings

Figure 28



Effect of Second Step Aging Time on Yield Strength of MA58 2" Square Hand Forgings.

Figure 29



Effect of Second Step Aging Time on Yield Strength of P/M MA39 2" Square Hand Forgings.

Figure 30

APPENDIX I - DEVELOPMENT OF METHOD FOR DETERMINATION OF MELTING TEMPERATURE IN P/M WROUGHT MATERIALS

Sheet and extrusion material in two alloys shown in Table 1, Appendix I used for identifying P/M melting in solution treatment was prepared by cold pressing powder to 85% density, preheating in flowing argon at 900 F for 4 hours, hot pressing at approximately 90 ksi and extruding or hot pressing. The sheet material was rolled from a 2" X 2" X 8" section of a hand forging made from a hot pressed compact (forging prepared by hammer forging). The sheet was prepared by hot rolling from 2" thick to 0.18" and cold rolling to 0.09" thick without intermediate anneals.

Both sheet and extrusion samples were solution treated at 900 to 1000 F for 2 hours, cold water quenched, naturally aged 6-7 days and artificially aged 24 hours at 248 F. Transverse tensile properties and metallographic examinations were accomplished on these materials to find evidence of the onset of melting.

RESULTS AND DISCUSSION

The results of metallographic examination and tensile property tests of P/M sheet and extrusions are shown in Table 1, Appendix I, for the actual solution heat treat temperatures used.

The 8.8% Zn, 3.4% Mg, 0.5% Cu, 0.76% Fe+Ni alloy (analog to MA39) reached a strength plateau at 924 F solution temperature while ductility was improved up to 942 F solution temperature. X-ray examination for soluble phases showned 921 F sufficient to dissolve all the Zn, Mg, and Cu in MA39 (Table 53, Footnote 4). Since a companion ingot material in the same alloy showed melting at 942 F metallographically, this temperature might be excessive for routine use. Examination of microstructures at 962 F shows no significant evidence of melting in the P/M extrusion sample (shown in Figure 1). Above 962 F, this alloy begins to show evidence internal porosity similar in appearance to high temperature oxidation, as shown in Figure 2, for 981 F. This process continues at higher temperatures, generating an untestable material with a microstructure as shown in Figure 3 at 1008 F.

The 7.9% Zn, 2.4% Mg, 1.0% Cu, 1.5% Fe+Ni alloy gives slightly different behavior than the above alloy. At 942 F, the alloy is on a yield strength plateau and at peak ductility. This alloy shows microstructural development at temperatures from 962 to 1008 F somewhat similar to that shown in figures 1 to 3.

Since both alloys show only modest improvement in strength above 942 F with an accompanying loss in ductility,

a solution temperature indicated by either a strength plateau or optimum ductility would probably be below the solidus of the alloy.

It appears that caution in examining microstructures is necessary. The porosity and blistering shown in these materials could be generated by adherent moisture or hydrogen on Al_2O_3 from the powder surface, which was not removed in the preheat operation (at 900 F for the materials tested). The alloy would not have to be molten for this moisture to be effective in generating internal porosity, since gas evolution from the entrapped oxide would take place for a solution temperature above the preheat temperature. If the preheat temperature were above the solution treatment temperature, subsequent solution treatment could be detrimental to properties by melting without generating internal porosity. Property tests then have to hold first significance in determining solution temperature limits. On this basis, 924 F appears to be a reasonable solution temperature for the 8.8% Zn, 3.4% Mg, 0.5% Cu, 0.76% Fe+Ni alloy, while 942 F could be used for the 7.9% Zn, 2.4% Mg, 1.0% Cu, 1.5% Fe+Ni alloy.

TABLE 1, APPENDIX I

EFFECT OF SOLUTION HEAT TREAT TEMPERATURE ON MECHANICAL PROPERTIES AND METALLOGRAPHIC APPEARANCE OF P/M EXTRUSIONS AND SHEET (3)

SHT Temp. (°F)	P/M Extrusions (1) Transverse Y.S. (ksi)	El. (%)	R of A (%)	Metallog. (Porosity)	Ingot Material (Metallog.)	P/M Sheet (2) Transverse Y.S. (ksi)	El. (%)	Metallog. (Porosity)	Ingot Material (Metallog.)
8.8 Zn, 3.4 Mg, 0.5 Cu, 0.76 Fe+Ni (Analog to MA39)									
904	96.8	2.8	5	None		88.0	4.5	None	
924 (4)	98	3.0	6			88.6	3.5		
942	97.9	3.5	6		Melted	88.8	6.5		
962	98.6	3.0	6	None		88.8	3.0	None	
981	96.8	3.0	4	Moderate		88.6	6.0	Moderate	Melted
1008	92.4	2.2	2	Severe				Severe	
7.9 Zn, 2.4 Mg, 1.0 Cu, 1.5 Fe+Ni									
904 (5)	85.9	4.5	6	None		78.2	5.2	None	
924	86.4	3.5	7			78.6	7.2		
942	86.8	8.0	10			77.4	7.2		
962	87.6	2.8	5	None	Porosity	77.3	8.0		
981	87.1	5.0	6	Slight	Cracked	78.9	7.2	None	Porosity
1008				Severe				Moderate	Melted

(1) Mechanical Test No. 021770A dated 3/3/70.

(2) Mechanical Test No. 021770A dated 2/17/70.

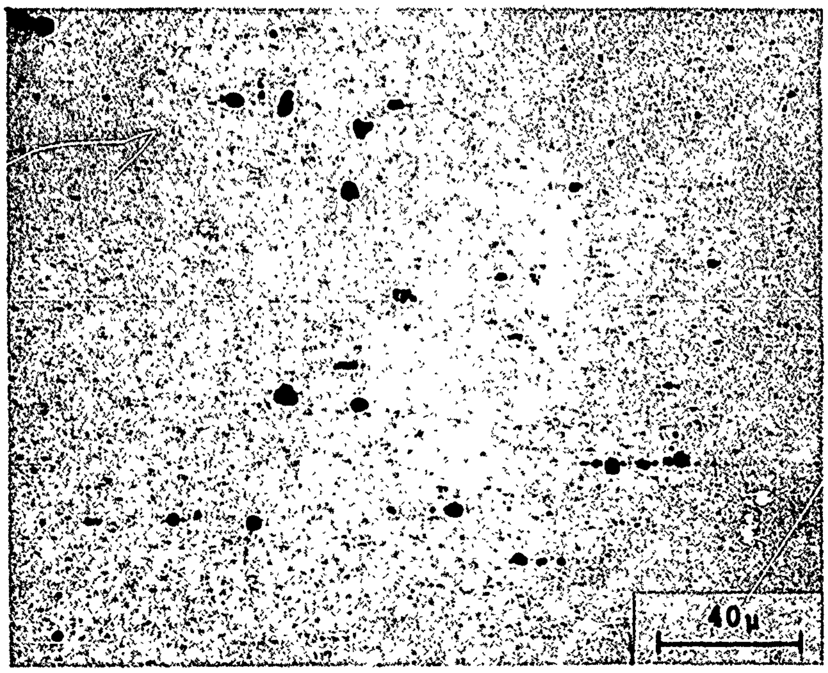
(3) All materials solution heat treated 2 hours (ammonium fluoborate atmosphere), CWQ, N.A. 6-7 days and aged 24 hours at 248 F.

(4) Physical Metallurgy Division X-ray Report 9363, 1-19-1970. SHT'd. 1/4" slices of MA39-2" φ Extru. @ 921 F 998 F, CWQ, No age; showed no soluable phases present at after any SHT.

(5) Physical Metallurgy Division X-ray Report 9656, 9-25-70. SHT'd. 1/4" slices of 2"φ Extrus. @ 860 F, CWQ, No age, showed V-small "M", Medium Mg_2Si.

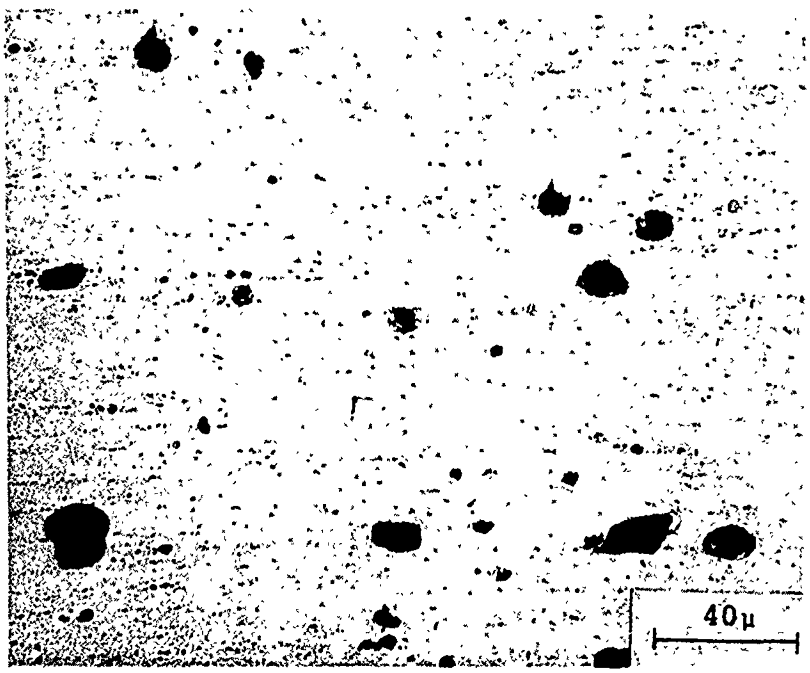
P/M extrusion solution heat treated at 962°F.
Comparable to extrusion SHT'd at 904°F.
(8.8 Zn, 3.4 Mg, 0.5 Cu, 0.8 Fe+Ni)
500X No etch

Figure 1, Appendix I



P/M extrusion solution heat treated at 981°F. Evidence of moderate internal porosity comparable to high temperature "oxidation" in appearance. (8.8 Zn, 3.4 Mg, 0.5 Cu, 0.8 Fe+Ni) 500X No etch

Figure 2, Appendix I



P/M extrusion solution heat treated at 1008°F. Evidence of severe internal porosity comparable in appearance to high temperature "oxidation." (8.8 Zn, 3.4 Mg, 0.5 Cu, 0.8 Fe+Ni)
500X No etch

Figure 3, Appendix I

APPENDIX II - FABRICATION OF P/M M16 RECEIVER FORGINGS MATERIAL PREPARATION AND TESTING

Extruded 1-7/8" diameter rod was prepared from two powder alloys (MA58 and MA39) listed in Table 1 (text) by cold pressing the powder isostatically to yield a compact of approximately 80% density. The cold compacts were approximately 7" diameter X 12" long. These compacts were preheated in flowing dry argon for 5 hours at 950 F, immediately hot pressed against a blind die and extruded from a 7-1/2" diameter cylinder to 1-7/8" diameter rod at less than 3 feet per minute extrusion speed.

Sections of rod of each alloy were cut to the required length as the starting material for the die forging of the M16 rifle lower receiver.

A set of lower receiver forgings of each alloy was produced by reheating the P/M extruded rod to 820 F, and forging on a mechanical press by a three-strike rod-to-finished-forging continuous sequence.

The resultant forgings were solution heat treated (890 F for MA58, 920 F for MA39) for 2 hours, cold water quenched, naturally aged 6 days, and artificially aged 24 hours at 250 F.

The forgings were etched after aging for observing microstructure and crack detection. The forgings were initially

immersed in a 5% NaOH solution at 140 F, water rinsed, immersed in a 50% nitric acid solution, water rinsed and air blast dried.

Sections of aged extrusions were exposed to the MASTMAASIS accelerated exfoliation test. The "as forged" surface and a surface 0.090" below the "as forged" surface were exposed for one week.

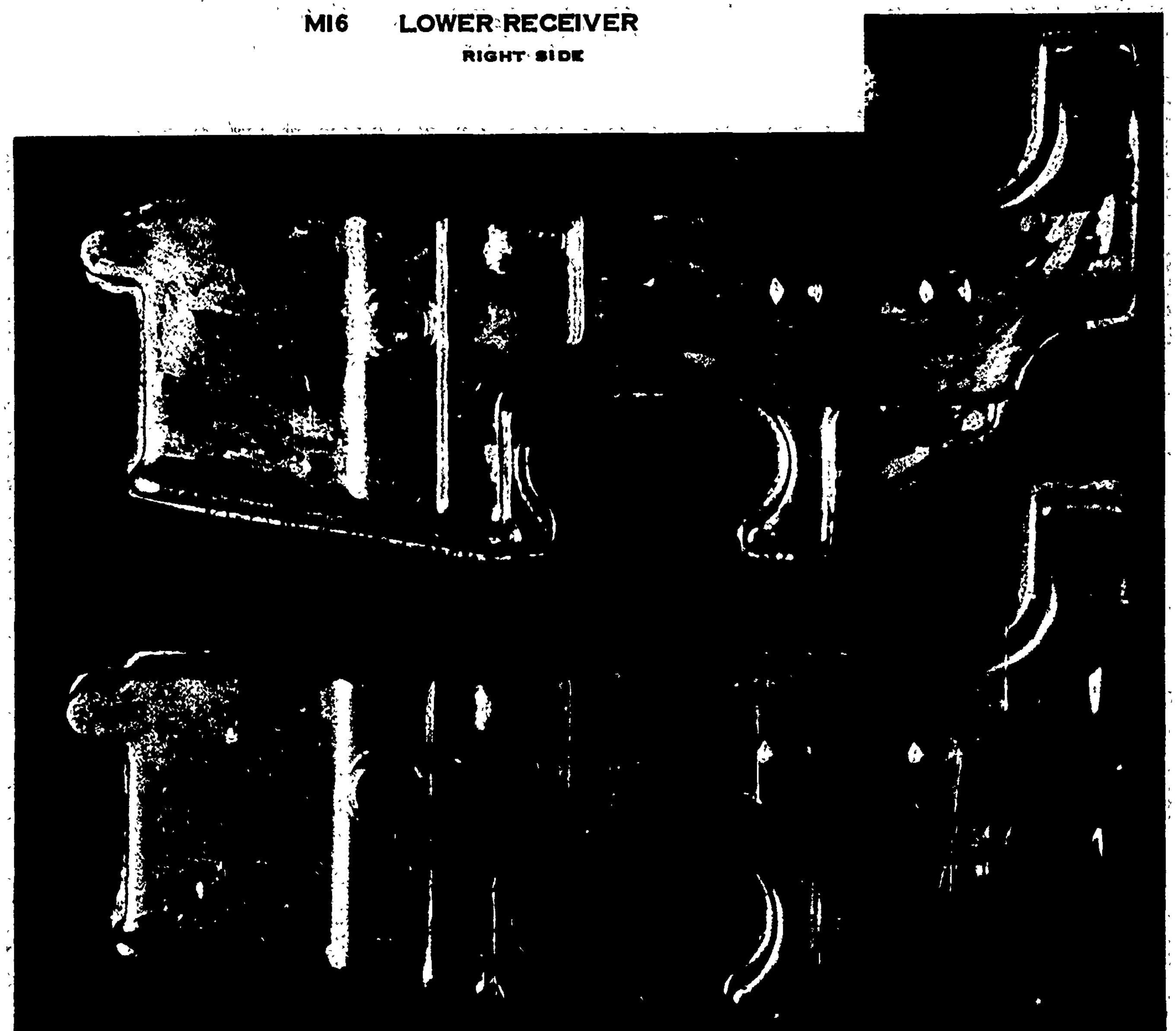
RESULTS AND DISCUSSION

Examination of the M16 lower receiver forgings showed considerable evidence of surface recrystallization in the pieces of MA58 alloy, and some evidence of surface recrystallization in selected portions of the MA39 forgings, as seen in Figures 1 and 2, Appendix II. Sections shown in Figures 3 and 4 show the extent of recrystallization below the surface in the receiver ring section (upper) and trigger guard strut section (lower) for MA58 (Figure 3 Appendix II) and MA39 (Figure 4 Appendix II). The sample locations can be seen as a faint dashed line in Figure 2 Appendix II on the P/M MA58 alloy forging.

The MA58 alloy forging (Figure 3 Appendix II) shows a considerably deeper recrystallized skin at both sample locations than does the MA39 alloy forging (Figure 4 Appendix II). The 0.8 Co in MA39 appears to hinder recrystallization, probably by nucleation control, judging from the large recrystallized grain sizes evident in the MA39 forgings.

The results of MASTMAASIS exfoliation tests are shown in Figure 5 Appendix II showing the sections of M16 Receivers exposed for one week. The surface recrystallized skin was apparently prone to exfoliate in both alloys, while only the MA58 forging in this temper showed exfoliation of the underlying unrecrystallized metal. The MA39 alloy forging, when unrecrystallized, appears resistant to exfoliation in this temper (80+ ksi longitudinal yield strength - Table 57 text).

M16 LOWER RECEIVER
RIGHT SIDE

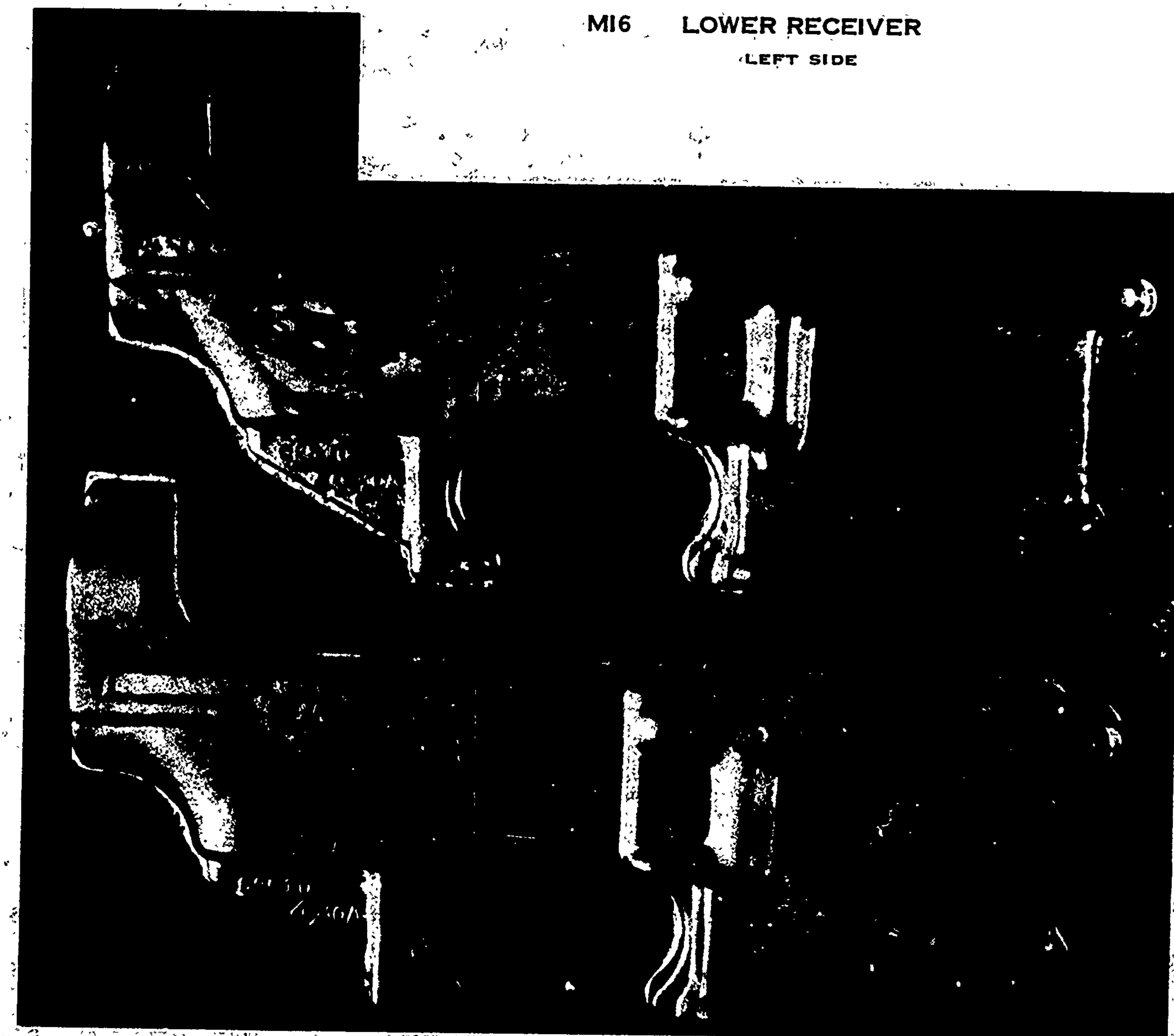


P M
MA58
ALLOY

P M
MA39
ALLOY

FIGURE I, APPENDIX II

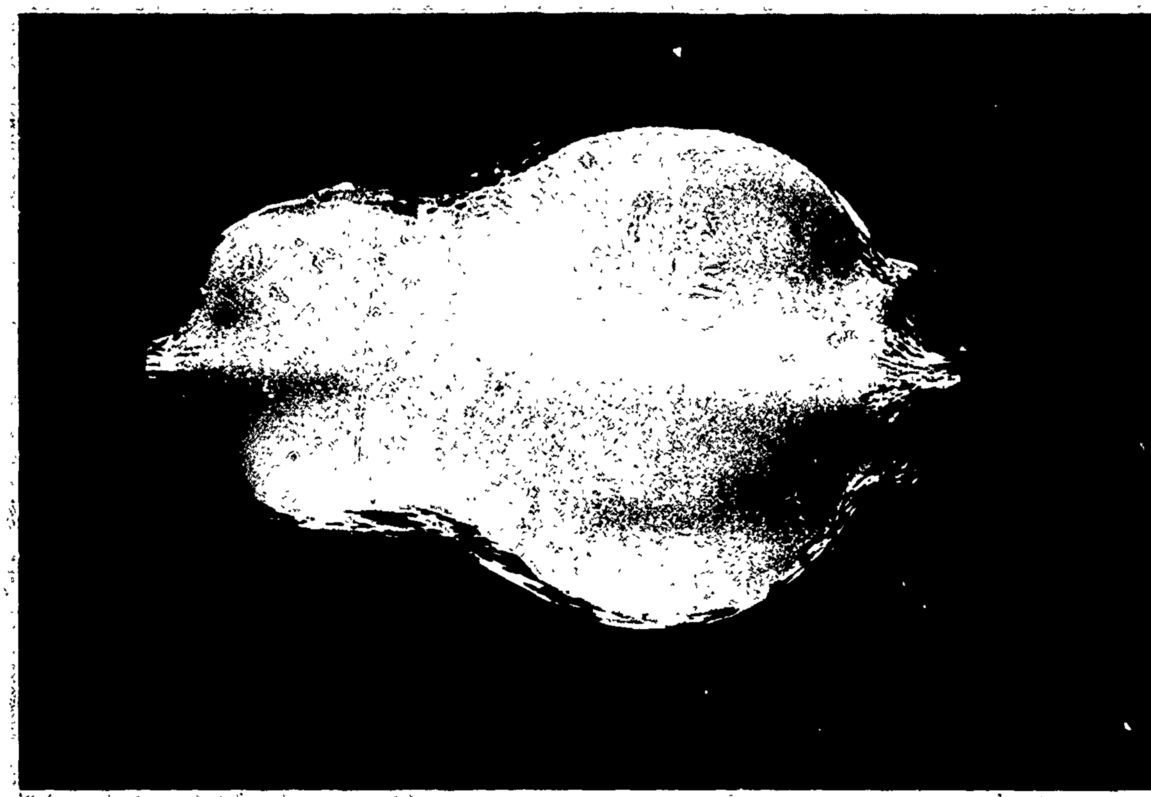
MI6 LOWER RECEIVER
LEFT SIDE



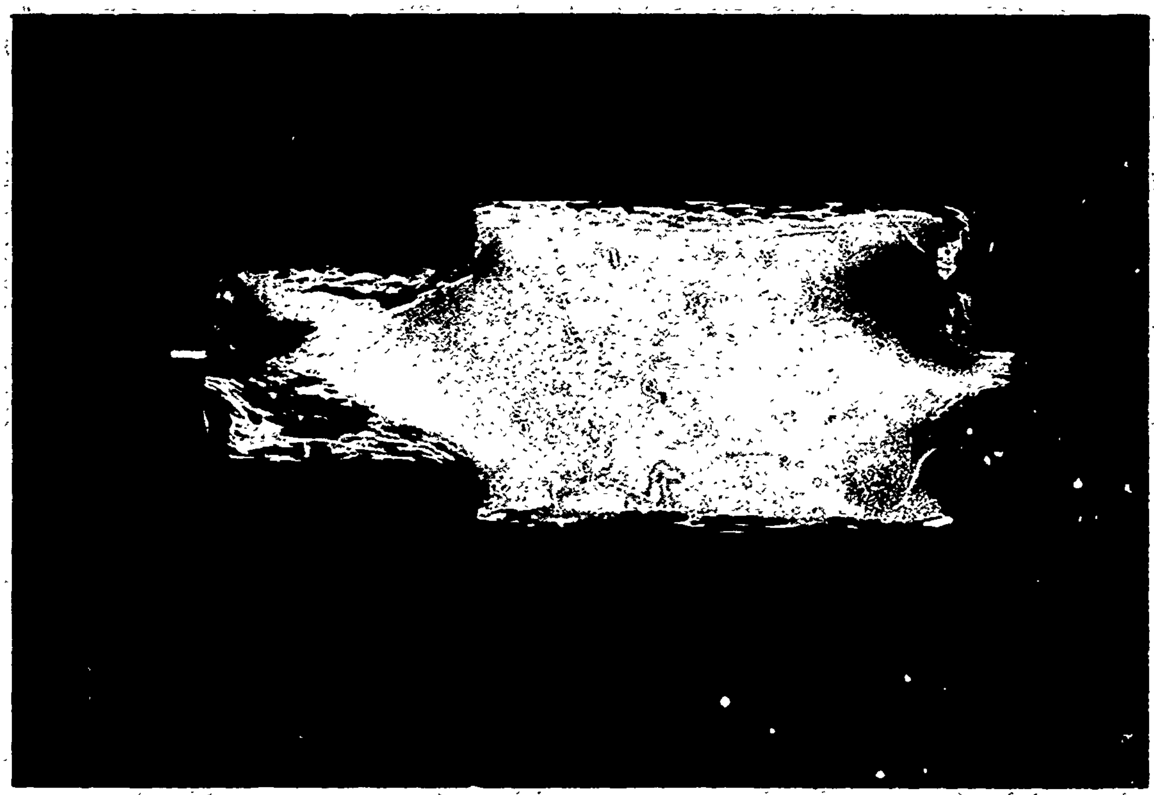
P M
MA58
ALLOY

P M
MA39
ALLOY

FIGURE 2, APPENDIX II

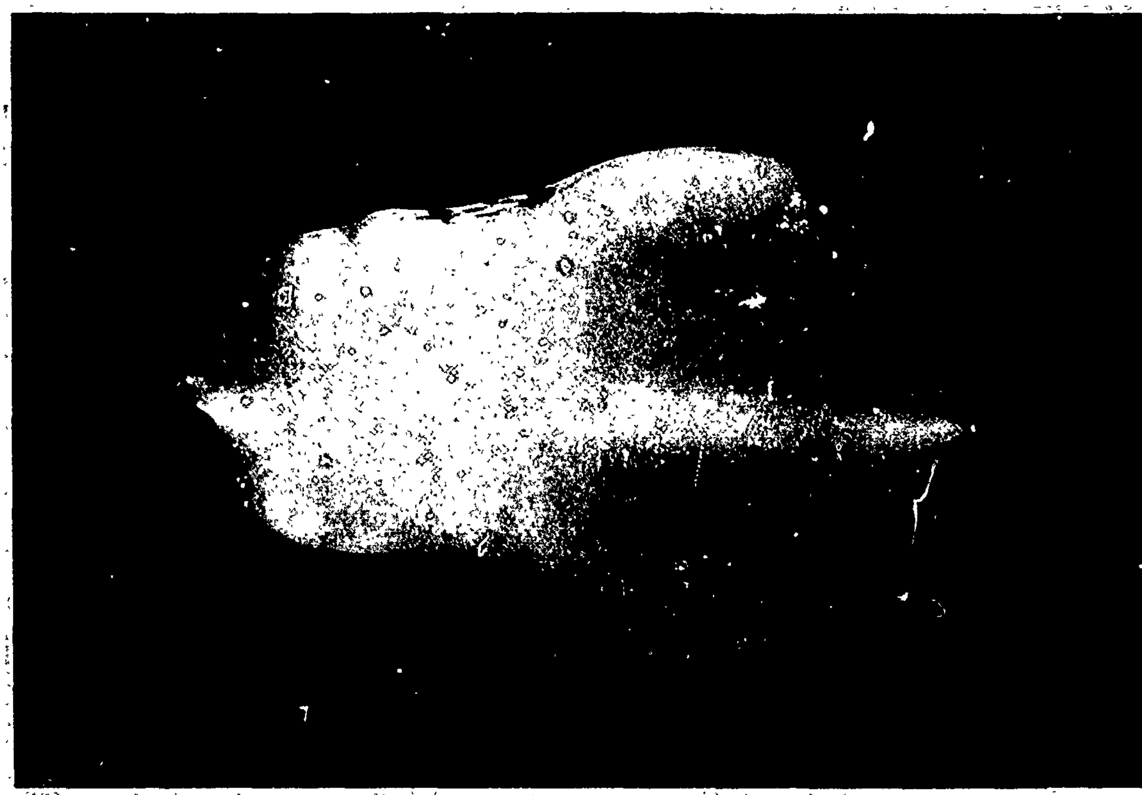


Cross Section of MA58 Alloy M16 Lower Receiver Through the Front Receiver Ring. (2X, Keller's Etch)

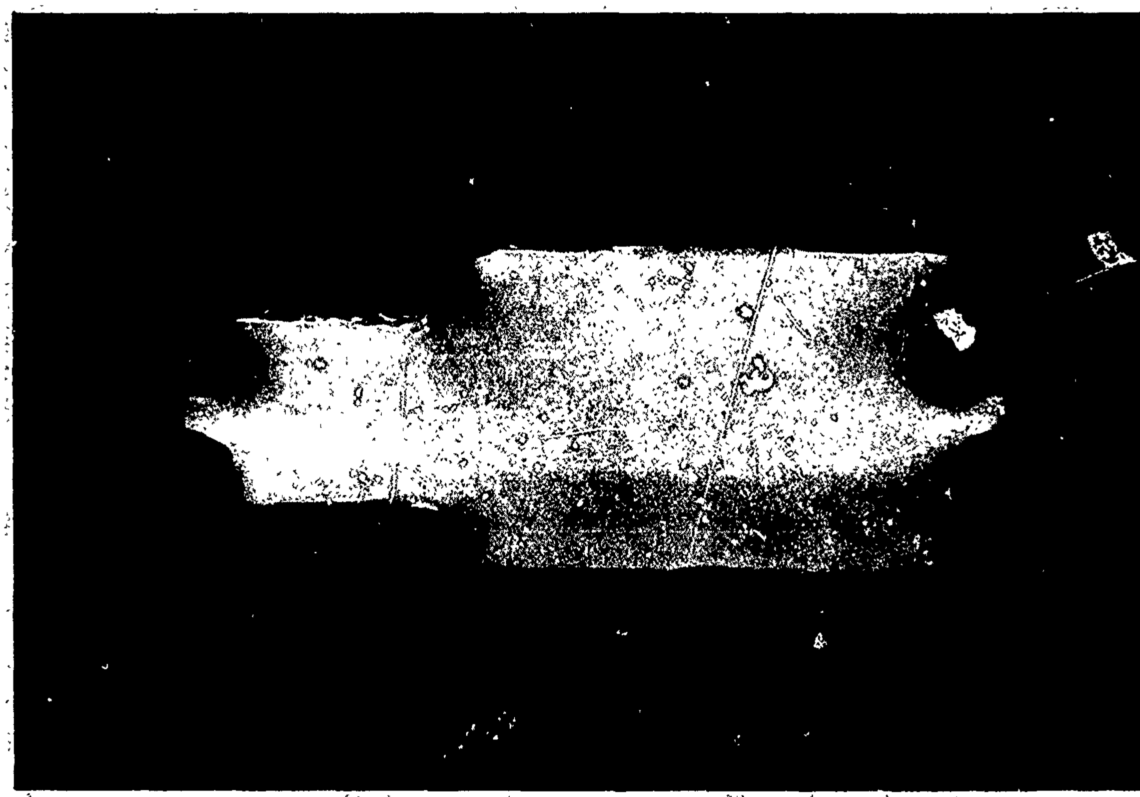


Cross Section of MA58 Alloy M16 Lower Receiver Through the Trigger Guard Strut. (2X, Keller's Etch)

Figure 3 - Appendix II



Cross Section of MA39 Alloy M16 Lower Receiver Through the Front Receiver Ring. (2X, Keller's Etch)



Cross Section of MA39 Alloy M16 Lower Receiver Through the Trigger Guard Strut. (2X, Keller's Etch)

Figure 4 - Appendix II

SECTION OF M16 RECEIVER FORGINGS AFTER ONE WEEK IN AN ACCELERATED EXFOLIATION TEST (MASTMAASIS)

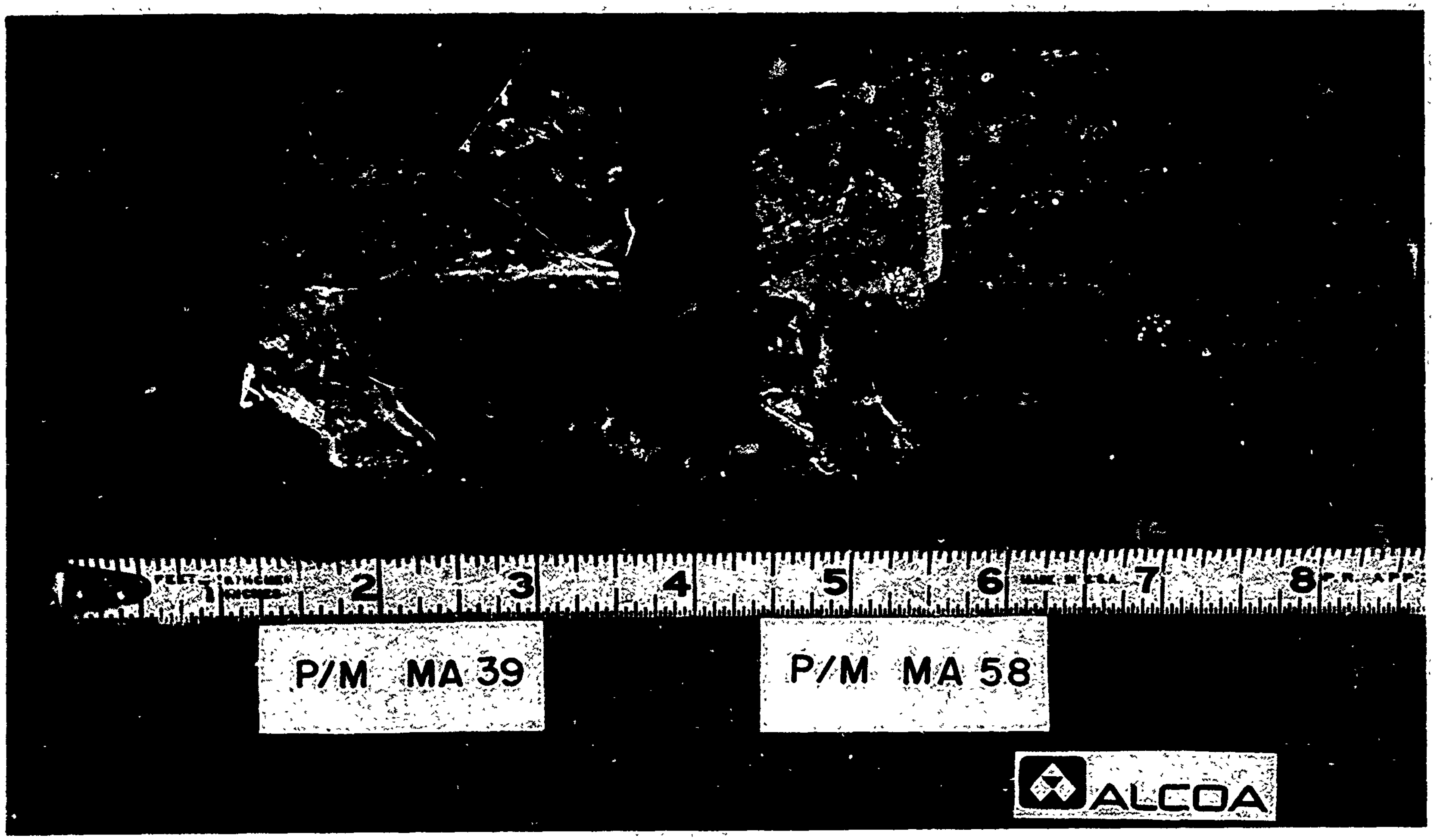


FIGURE 5 — APPENDIX II

TABLE 1, APPENDIX III

MA58-EFFECT OF GREEN DENSITY ON LONGITUDINAL TENSILE PROPERTIES

Preheat Temp. (°F)	Preheat Time (Hr)	Hot Coin Press. (ksi)	Forging Code No. Green Density 70%	Forging Code No. Green Density 80%	T.S. (ksi) Green Density 70%	T.S. (ksi) Green Density 80%	Y.S. (ksi) Green Density 70%	Y.S. (ksi) Green Density 80%
900	1	90	E1	E4	75.8	75.7	67.7	68.0
900	1	90	E1	E4	75.6	74.8	67.2	67.2
900	20	90	H1	H4	76.2	73.1	68.0	64.9
900	20	90	H1	H4	76.0	73.5	68.4	65.2
1000	1	90	E3	E5	70.8	77.5	61.3	69.8
1000	1	90	E3	E5	70.1	77.2	60.8	69.2
1000	20	90	H3	H5	76.2	74.3	69.0	66.8
1000	20	90	H3	H5	77.0	73.4	69.8	65.9
950	5	30	C1	C3	73.8	74.3	66.7	66.8
950	5	30	C1	C3	74.3	73.8	67.1	66.7
950	5	60	D1	D3	73.4	75.3	64.9	67.5
950	5	60	D1	D3	73.5	75.3	63.9	66.9
950	5	90	A13	B25	75.6	72.8	68.5	65.4
950	5	90	A13	B25	73.0	72.8	66.8	65.1
				n =	14	14	14	14
				Avg.	74.4	74.6	66.4	66.8
				Σ dev^2	56.30	29.61	98.22	28.78
				Std dev	2.1	1.5	2.7	1.5
				Student's t =	.29		.48	
				d.f. =	26		26	
				P(1) =	60%		70%	

Notes (1) P = Probability that difference between averages is significant.

TABLE 1, APPENDIX III

MA58-EFFECT OF GREEN DENSITY ON LONGITUDINAL TENSILE PROPERTIES

Preheat Temp. (°F)	Preheat Time (Hr)	Hot Coin Press. (ksi)	Forging Code No. Green Density 70%	Forging Code No. Green Density 80%	El (%) Green Density 70%	El (%) Green Density 80%	NTS (ksi) Green Density 70%	NTS (ksi) Green Density 80%
900	1	90	E1	E4	14.0	14.0	97.5	95.0
900	1	90	E1	E4	14.0	16.0	95.8	96.4
900	20	90	H1	H4	16.0	16.0	82.4	89.6
900	20	90	H1	H4	16.0	14.0	85.3	86.8
1000	1	90	E3	E5	10.0	16.0	94.4	91.5
1000	1	90	E3	E5	14.0	16.0	95.5	96.7
1000	20	90	H3	H5	16.0	16.0	92.9	90.3
1000	20	90	H3	H5	16.0	18.0	92.4	88.8
950	5	30	C1	C3	16.0	14.0	91.4	90.4
950	5	30	C1	C3	20.0	18.0	91.9	91.0
950	5	60	D1	D3	14.0	16.0	88.4	89.1
950	5	60	D1	D3	10.0	16.0	91.9	82.7
950	5	90	A13	B25	16.0	18.0	89.8	91.5
950	5	90	A13	B25	16.0	20.0	88.6	92.0

	El 70%	El 80%	NTS 70%	NTS 80%
n =	14	14	14	14
Avg	14.8	16.3	91.3	90.8
Σ dev²	85.72	38.86	223.60	176.67
Std dev	2.57	1.73	4.15	3.69
Student's t =	1.81			
d.f. =	26			
P(1) =	>95%			

Notes (1) P = Probability Difference.

TABLE 2, APPENDIX III

MA58-EFFECT OF GREEN DENSITY ON TRANSVERSE PROPERTIES

Preheat Temp. (°F)	Preheat Time (Hr)	Hot Coin Press. (ksi)	Forging Code No. Green Density 70%	Forging Code No. Green Density 80%	T.S. (ksi) Green Density 70%	T.S. (ksi) Green Density 80%	Y.S. (ksi) Green Density 70%	Y.S. (ksi) Green Density 80%
900	1	90	E1	E4	73.7	74.1	65.0	65.2
900	1	90	E1	E4	71.8	74.5	63.0	65.1
900	20	90	H1	H4	71.2	69.6	63.5	60.6
900	20	90	H1	H4	71.7	68.9	63.6	61.1
1000	1	90	E3	E5	70.8	70.7	61.3	62.0
1000	1	90	E3	E5	70.1	74.8	60.8	65.0
1000	20	90	H3	H5	70.1	69.0	66.8	60.7
1000	20	90	H3	H5	74.5	68.6	66.0	59.9
950	5	30	C1	C3	73.3	70.0	-- (2)	60.6
950	5	30	C1	C3	73.1	69.2	65.3	60.4
950	5	60	D1	D3	73.4	69.1	64.9	62.8
950	5	60	D1	D3	73.5	71.0	63.9	62.1
950	5	90	A13	B25	72.3	68.4	64.7	59.5
950	5	90	A13	B25	72.0	68.7	64.7	59.2

	T.S. 70%	T.S. 80%	Y.S. 70%	Y.S. 80%
n =	14	14	13	14
Avg	72.2	70.5	64.1	61.7
Σ dev^2	24.90	68.54	35.17	56.0
Std dev	1.38	2.30	1.71	2.07
Student's t =	2.37		3.26	
d.f. =	26		25	
P(4) =	98.5%		99.5%	

Notes (1) To be retested.
(2) Invalid Test Parameter.
(3) To be Determined.
(4) P = Probability that difference between averages is significant.

TABLE 2, APPENDIX III

MA58-EFFECT OF GREEN DENSITY ON TRANSVERSE PROPERTIES

Preheat		Hot Coin	Forging Code No.		El (%)		NTS (ksi)	
Temp.	Time	Press.	Green Density		Green Density		Green Density	
(°F)	(Hr)	(ksi)	70%	80%	70%	80%	70%	80%
900	1	90	E1	E4	8.0	12.0	65.6	41.4
900	1	90	E1	E4	14.0	12.0	73.7	56.0
900	20	90	H1	H4	6.0	6.0	36.4	55.5
900	20	90	H1	H4	8.0	6.0	40.1	42.5
1000	1	90	E3	E5	10.0	8.0	49.8	-- (2)
1000	1	90	E3	E5	14.0	8.0	55.6	54.2
1000	20	90	H3	H5	-- (2)	16.0	60.2	43.8
1000	20	90	H3	H5	8.0	16.0	53.4	51.0
950	5	30	C1	C3	14.0	8.0	46.0	48.0
950	5	30	C1	C3	8.0	6.0	47.8	51.9
950	5	60	D1	D3	14.0	6.0	44.4	53.4
950	5	60	D1	D3	10.0	6.0	49.3	49.0
950	5	90	A13	B25	10.0	8.0	53.9	54.1
950	5	90	A13	B25	8.0	14.0	57.4	46.0
				n =	13	14	14	13
				Avg	10.2	9.4	52.4	49.8
				Σ dev^2	99.70	187.44	1277.04	305.76
				Std dev	2.88	3.80	9.91	5.05
				Student's t =				
				P(4) =	Not signif.		Not signif.	

Notes (1) To be retested.
(2) Invalid Test Parameter.
(3) To be Determined.
(4) P = Probability that difference between averages is significant.

TABLE 3, APPENDIX III

MA39-EFFECT OF GREEN DENSITY ON LONGITUDINAL TENSILE PROPERTIES

Preheat Temp. (°F)	Preheat Time (Hr)	Hot Coin Press. (ksi)	Forging Code No. Green Density 70%	Forging Code No. Green Density 80%	T.S. (ksi) Green Density 70%	T.S. (ksi) Green Density 80%	Y.S. (ksi) Green Density 70%	Y.S. (ksi) Green Density 80%
900	1	90	E6	E8	75.0	73.6	65.3	63.9
900	1	90	E6	E8	75.6	73.6	65.7	64.2
900	20	90	H6	H8	73.2	74.3	62.8	64.7
900	20	90	H6	H8	72.9	75.4	62.3	65.3
1000	1	90	E7	E9	72.7	73.8	63.0	65.4
1000	20	90	E7	E9	73.4	75.1	63.3	66.1
1000	20	90	H7	H9	74.8	75.4	64.8	66.5
1000	20	90	H7	H9	76.4	75.5	66.7	66.6
950	5	30	C5	C7	74.0	72.1	63.4	62.5
950	5	30	C5	C7	74.3	71.1	64.2	61.0
950	5	60	D5	D7	73.7	73.3	64.0	64.0
950	5	60	D5	D7	74.4	73.8	65.0	64.6
950	5	90	A14	B26	73.6	73.1	63.6	63.6
950	5	90	A14	B26	72.9	-- (1)	61.0	65.0
				n =	14	13	14	14
				Avg	74.06	73.8	63.94	64.5
				Σ dev^2	15.60	20.96	28.84	30.53
				Std dev	1.10	1.32	1.49	1.53

Notes (1) Invalid Test Parameter.

TABLE 3, APPENDIX III

MA39-EFFECT OF GREEN DENSITY ON LONGITUDINAL TENSILE PROPERTIES

Preheat Temp. (°F)	Preheat Time (Hr)	Hot Coin Press. (ksi)	Forging Code No. Green Density 70%	Forging Code No. Green Density 80%	El (%) Green Density 70%	El (%) Green Density 80%	NTS (ksi) Green Density 70%	NTS (ksi) Green Density 80%
900	1	90	E6	E8	16.0	12.0	82.9	83.8
900	1	90	E6	E8	16.0	14.0	80.5	52.8
900	20	90	H6	H8	15.0	15.0	78.2	80.5
900	20	90	H6	H8	15.0	15.0	75.4	70.4
1000	1	90	E7	E9	16.0	16.0	78.9	85.6
1000	20	90	E7	E9	16.0	16.0	79.2	84.9
1000	20	90	H7	H9	15.0	14.0	74.2	74.1
1000	20	90	H7	H9	14.0	14.0	72.8	74.1
950	5	30	C5	C7	16.0	14.0	78.2	82.1
950	5	39	C5	C7	16.0	14.0	80.2	83.4
950	5	60	D5	D7	16.0	16.0	80.3	82.5
950	5	60	D5	D7	16.0	16.0	80.7	84.7
950	5	90	A14	B26	16.0	16.0	80.3	84.2
950	5	90	A14	B26	14.0	16.0	80.3	81.8
				n =	14	14	14	14
				Avg	15.5	14.9	78.7	78.9
				Σ dev^2	7.5	19.72	101.58	1020.61
				Std dev	.76	1.23	2.80	8.86

Student's t = 1.55

TABLE 4, APPENDIX III

MA39-EFFECT OF GREEN DENSITY ON TRANSVERSE TENSILE PROPERTIES

Preheat Temp. (°F)	Preheat Time (Hr)	Hot Coin Press. (ksi)	Forging Code No. Green Density 70%	Forging Code No. Green Density 80%	T.S. (ksi) Green Density 70%	T.S. (ksi) Green Density 80%	Y.S. (ksi) Green Density 70%	Y.S. (ksi) Green Density 80%
900	1	90	E6	E8	73.2	71.5	63.0	59.6
900	1	90	E6	D8	74.1	70.2	64.2	58.9
900	20	90	H6	H8	72.0	71.1	62.1	61.9
900	20	90	H6	H8	-- [1]	71.3	61.1	61.4
1000	1	90	E7	E9	71.6	73.4	60.8	62.6
1000	1	90	E7	E9	72.6	73.5	61.8	62.4
1000	20	90	H7	H9	73.1	72.4	63.7	60.9
1000	20	90	H7	H9	73.7	72.3	63.8	61.4
950	5	30	C5	C7	68.8	70.0	60.2	58.7
950	5	30	C5	C7	69.6	-- [1]	61.1	64.8
950	5	60	D5	D7	70.4	71.3	61.4	61.2
950	5	60	D5	D7	71.9	-- [1]	62.0	60.7
950	5	90	A14	B26	70.4	69.0	59.7	61.5
950	5	90	A14	B26	69.0	72.4	59.0	62.0
				n =	13	12	14	14
				Avg	71.6	71.5	61.7	61.3
				Σ dev^2	38.21	20.32	31.81	32.0
				Std dev	11.78	1.36	1.56	1.57

Notes (1) Invalid Parameter.

TABLE 4, APPENDIX III

MA39-EFFECT OF GREEN DENSITY ON TRANSVERSE TENSILE PROPERTIES

Preheat		Hot Coin	Forging Code No.		El (%)		NTS (ksi)	
Temp.	Time	Press.	Green Density		Green Density		Green Density	
(°F)	(Hr)	(ksi)	70%	80%	70%	80%	70%	80%
900	1	90	E6	E8	10.0	12.0	59.0	65.3
900	1	90	E6	E8	6.0	10.0	49.8	52.8
900	20	90	H6	H8	12.0	6.0	28.5	41.2
900	20	90	H6	H8	-- [1]	6.0	29.3	41.0
1000	1	90	E7	E9	10.0	8.0	44.3	52.5
1000	1	90	E7	E9	10.0	8.0	45.2	53.3
1000	20	90	H7	H9	8.0	9.0	39.7	53.3
1000	20	90	H7	H9	8.0	9.0	43.2	47.8
950	5	30	C5	C7	4.0	8.0	47.2	47.2
950	5	30	C5	C7	4.0	-- [1]	43.4	42.4
950	5	60	D5	D7	4.0	10.0	51.0	44.1
950	5	60	D5	D7	4.0	-- [1]	46.8	42.8
950	5	90	A14	B26	10.0	4.0	44.2	43.6
950	5	90	A14	B26	4.0	6.0	52.5	48.0

	El 70%	El 80%	NTS 70%	NTS 80%
n =	13	12	14	14
Avg	7.2	8.0	44.6	48.2
Σ dev²	108.31	54.00	870.7	586.88
Std dev	3.00	2.21	8.18	6.72
Student's t =	.75		1.27	
P =	<80%		<90%	

Notes: (1) Invalid Parameter.

TABLE 5, APPENDIX III

EFFECT OF COLD COMPACT METHOD ON LONGITUDINAL PROPERTIES

	Hot Compact Pressure (ksi)	Tensile Strength(ksi) Uniaxial	Tensile Strength(ksi) Isostatic	Yield Strength(ksi) Uniaxial	Yield Strength(ksi) Isostatic	% Elongation Uniaxial	% Elongation Isostatic	NTS/YS Uniaxial	NTS/YS Isostatic
MA58 Alloy									
	30	74.0	73.3	66.9	66.8	18.0	16.0	1.37	1.40
	60	75.6	74.4	68.3	68.2	18.0	16.0	1.32	1.31
	90	74.3	73.9	67.6	67.2	16.0	18.0	1.31	1.42
Mean	Avg.	74.6	73.9	67.6	67.4	17.33	16.67	1.33	1.38
	Σ dev ^{2}	1.45	.61	.98	1.04	2.67	2.67	.002	.007
Student's t =		1.19		.34		.70		.13	
P		<90%							
MA39 Alloy									
	30	74.2	75.8	63.8	65.4	16.0	15.0	1.26	1.07
	60	74.0	75.3	64.5	64.4	16.0	16.0	1.25	1.14
	90	73.2	74.9	62.3	64.5	15.0	14.0	1.29	1.21
	Avg.	73.8	75.33	63.53	64.77	15.67	15.0	1.27	1.14
	dev	.56	.41	2.53	.61	.67	2.00	.0087	.0098
Student's t =		.37		2.65		2.00		.22	
P				96%		94%			

(1) P = probability that difference between averages is significant.

TABLE 6, APPENDIX III

EFFECT OF COLD COMPACT METHOD ON TRANSVERSE PROPERTIES

	Hot Compact Pressure (ksi)	Tensile Strength(ksi)		Yield Strength(ksi)		% Elongation		NTS/YS	
		Uniaxial	Isostatic	Uniaxial	Isostatic	Uniaxial	Isostatic	Uniaxial	Isostatic
MA58 Alloy	30	73.2	70.8	65.3	64.0	11.0	8.0	0.72	1.00
	60	73.4	75.0	64.4	67.8	12.0	7.0	.73	.89
	90	72.2	72.4	64.7	64.8	9.0	8.0	.86	1.20
	Avg.	72.93	72.73	64.8	65.53	10.67	7.67	.77	1.03
	Σ dev²	.83	8.99	.42	8.03	4.67	.67	.012	.049
Student's t =		4.99		3.60		4.24		2.34	
P		100%		98%		99%		97%	
MA39 Alloy	30	69.2	71.3	60.6	61.6	4.0	6.0	.75	.81
	60	71.2	72.7	61.7	60.4	4.0	6.0	.79	.79
	90	69.7	69.7	59.4	59.4	7.0	4.0	.81	.90
	Avg.	70.03	71.23	60.57	60.47	5.0	5.33	.78	.83
	dev	2.17	4.51	2.65	2.43	6.0	2.67	.0019	.0069
Student's t =		2.23		.24		2.77		.0055	
P		97%		59%		97%			

(1) P = probability that difference between averages is significant.

TABLE 7. APPENDIX III

MA58-EFFECT OF PREHEAT TEMPERATURE ON LONGITUDINAL TENSILE PROPERTIES

Green Density (%)	Preheat Time (Hr)	Hot Coin Press. (ksi)	Forging Code No. Preheat Temp. (°F)			T.S. (ksi) Preheat Temp. (°F)			Y.S. (ksi) Preheat Temp. (°F)		
			900	950	1000	900	950	1000	900	950	1000
70	1	90	E1	E2	E3	75.8	76.9	72.8	67.7	69.5	65.2
70	1	90	E1	E2	E3	75.6	76.3	73.0	67.2	69.2	65.7
70	5	90	J1	A13	J2	76.9	72.3	76.6	68.7	64.7	69.5
70	5	90	J1	A13	J2	76.4	72.0	76.2	67.9	64.7	68.9
70	20	90	H1	H2	H3	76.2	78.2	76.2	68.0	70.2	69.0
70	20	90	H1	H2	H3	76.0	76.2	77.0	68.4	68.1	69.8
80	5	30	C2	C3	C4	73.6	74.3	73.1	66.0	66.8	65.6
80	5	30	C2	C3	C4	73.7	73.8	73.5	66.2	66.7	66.6
80	5	60	D2	D3	D4	75.9	75.3	74.0	67.8	67.5	67.1
80	5	60	D2	D3	D4	75.9	75.3	75.9	67.8	66.9	68.9
80	5	90	J3	B4	J4	74.1	75.4	72.2	66.8	69.2	65.0
80	5	90	J3	B4	J4	73.8	75.1	74.3	66.3	69.5	66.8
					n =	12	12	12	12	12	12
					Avg	75.3	75.09	74.6	67.41	67.75	67.3
					Σ dev^2	15.26	35.45	32.09	8.72	37.85	35.06
					Std dev	1.18	1.80	1.71	0.89	1.85	1.78

TABLE 7, APPENDIX III

MA58 EFFECT OF PREHEAT TEMPERATURE ON LONGITUDINAL TENSILE PROPERTIES

Green Density (%)	Preheat Time (Hr)	Hot Coin Press. (ksi)	Forging Code No. Preheat Temp. (°F) 900	950	1000	El (%) Preheat Temp. (°F) 900	950	1000	NTS (ksi) Preheat Temp. (°F) 900	950	1000
70	1	90	E1	E2	E3	14.0	14.0	16.0	97.5	90.8	94.4
70	1	90	E1	E2	E3	14.0	16.0	16.0	95.8	96.0	95.5
70	5	90	J1	A13	J2	14.0	10.0	16.0	92.0	89.8	90.7
70	5	90	J1	A13	J2	14.0	8.0	16.0	91.2	88.6	95.3
70	20	90	H1	H2	H3	16.0	14.0	16.0	82.4	86.7	92.9
70	20	90	H1	H2	H3	16.0	14.0	16.0	85.3	85.3	92.4
80	5	30	C2	C3	C4	20.0	14.0	16.0	86.3	90.4	87.8
80	5	30	C2	C3	C4	18.0	18.0	16.0	87.3	91.0	89.4
80	5	60	D2	D3	D4	12.0	16.0	18.0	83.8	89.1	92.7
80	5	60	D2	D3	D4	14.0	16.0	18.0	89.9	82.7	94.4
80	5	90	J3	B4	J4	16.0	18.0	14.0	86.7	90.3	94.4
80	5	90	J3	B4	J4	16.0	16.0	18.0	90.4	95.8	90.9
					n =	12	12	12	12	12	12
					Avg	15.3	14.50	16.3	89.0	89.7	92.6
					Σ dev²	50.67	97.0	14.67	234.83	159.62	65.40
					Std dev	2.15	2.96	1.15	4.62	3.81	2.44
					Student's t =	1.27	2.37			2.39	2.22
					d.f. =				22		
					P =	<90%	≃98%			98%	98%

TABLE 8, APPENDIX III

MA58 -EFFECT OF PREHEAT TEMPERATURE ON TRANSVERSE TENSILE PROPERTIES

Green Density (%)	Preheat Time (Hr)	Hot Coin Press. (ksi)	Forging Code No. Preheat Temp. (°F) 900	950	1000	T.S. (ksi) Preheat Temp. (°F) 900	950	1000	Y.S. (ksi) Preheat Temp. (°F) 900	950	1000
70	1	90	E1	E2	E3	73.7	74.7	70.8	65.0	65.0	61.3
70	1	90	E1	E2	E3	71.8	75.8	70.1	63.0	65.6	60.8
70	5	90	J1	A13	J2	70.0	72.3	73.4	62.1	64.7	64.7
70	5	90	J1	A13	J2	--[4]	72.0	73.4	62.5	64.7	64.2
70	20	90	H1	H2	H3	71.2	68.6	--[4]	63.5	63.2	66.8
70	20	90	H1	H2	H3	71.7	71.8	74.5	63.6	63.3	66.0
80	5	30	C2	C3	C4	72.8	70.0	69.0	64.9	60.6	60.0
80	5	30	C2	C3	C4	73.8	69.2	68.8	65.7	60.4	60.0
80	5	60	D2	D3	D4	75.3	69.1	71.8	67.0	62.8	63.8
80	5	60	D2	D3	D4	70.3	71.0	72.5	65.1	62.1	64.8
80	5	90	J3	B	J4	70.8	68.4	71.3	62.9	59.5	62.8
80	5	90	J3	B	J4	71.4	68.7	71.1	63.1	59.2	62.7
					n =	11	12	11	12	12	12
					Avg	72.1	71.0	71.5	64.0	62.6	63.2
					Σ dev^2	27.08	65.76	33.56	24.21	54.78	57.23
					Std dev	1.65	2.44	1.83	1.48	2.23	2.28
					Student's t =					1.81	
					d.f. =					22	
					p =					≈ 95.5%	

Notes:
(1) To be Retested.
(2) To be Determined.
(3) NC - No Forgings Prepared.
(4) Invalid Test Parameter.

TABLE 8, APPENDIX III

MA58-EFFECT OF PREHEAT TEMPERATURE ON TRANSVERSE TENSILE PROPERTIES

Green Density (%)	Preheat Time (Hr)	Hot Coin Press. (ksi)	Forging Code No. Preheat Temp. (°F)			El (%) Preheat Temp. (°F)			NTS (ksi) Preheat Temp. (°F)		
			900	950	1000	900	950	1000	900	950	1000
70	1	90	E1	E2	E3	8.0	12.0	10.0	65.6	61.2	49.8
70	1	90	E1	E2	E3	14.0	10.0	14.0	73.7	60.7	55.6
70	5	90	J1	A13	J2	6.0	10.0	14.0	45.7	53.9	51.9
70	5	90	J1	A13	J2	-- [4]	8.0	10.0	35.3	57.4	56.1
70	20	90	H1	H2	H3	6.0	4.0	-- [4]	36.4	36.9	60.2
70	20	90	H1	H2	H3	8.0	8.0	8.0	40.1	36.9	53.4
80	5	30	C2	C3	C4	6.0	8.0	6.0	49.5	48.0	54.1
80	5	30	C2	C3	C4	6.0	6.0	8.0	44.4	51.9	58.2
80	5	60	D2	D3	D4	6.0	6.0	10.0	52.7	50.3	62.0
80	5	60	D2	D3	D4	4.0	6.0	12.0	53.6	53.5	57.4
80	5	90	J3	B	J4	10.0	8.0	14.0	39.0	54.1	46.9
80	5	90	J3	B	J4	6.0	14.0	12.0	42.2	46.0	49.5
					n =	11	12	11	12	12	12
					Avg	7.3	8.3	10.7	48.2	50.9	54.6
					Σ dev²	74.18	86.67	74.19	1516.72	696.16	227.53
					Std dev	2.72	2.81	2.72	11.74	7.96	4.55
					Student's t =		≃.9	2.08			
					d.f. =			21			
					p =			97.5%			
					t =		2.93			1.76	
					d.f. =		20			22	
					p =		>99.5%			95%	

Notes:
(1) To be Retested.
(2) To be Determined.
(3) NC - No Forgings Prepared.
(4) Invalid Test Parameter.

TABLE 9, APPENDIX III

MA39-EFFECT OF PREHEAT TEMPERATURE ON LONGITUDINAL TENSILE PROPERTIES

Green Density (%)	Preheat Time (Hr)	Hot Coin Press. (ksi)	Forging Code No. Preheat Temp. (°F)			T.S. (ksi) Preheat Temp. (°F)			Y.S. (ksi) Preheat Temp. (°F)		
			900	950	1000	900	950	1000	900	950	1000
70	1	90	E6	NC	E7	75.0	--	72.7	65.3	--	63.0
70	1	90	E6	NC	E7	75.6	--	73.4	65.7	--	63.3
70	20	90	H6	NC	H7	73.2	--	74.8	62.1	--	64.8
70	20	90	H6	NC	H7	72.9	--	76.4	61.1	--	66.7
80	1	90	E8	NC	E9	73.6	--	73.8	63.9	--	65.4
80	1	90	E8	NC	E9	73.6	--	75.1	64.2	--	66.1
80	20	90	H8	NC	H9	74.3	--	75.4	64.7	--	66.5
80	20	90	H8	NC	H9	75.4	--	75.5	65.3	--	66.6
80	5	60	D6	D7	D8	74.7	73.3	75.9	65.3	64.0	67.2
80	5	60	D6	D7	D8	75.0	73.8	76.1	65.6	64.6	67.3
80	5	90	J5	B11	J6	72.6	75.5	74.7	62.1	66.5	65.6
80	5	90	J5	B11	J6	73.7	77.9	75.1	60.6	68.5	66.0
					n =	4	4	4	4	4	4
					Avg	74.0	75.1	75.5	63.4	65.9	66.5
					Σ dev^2	3.54	12.93	1.31	17.98	12.42	2.19
					Std dev	1.09	2.08	0.66	2.44	2.03	0.85
					n =	12		12	12		12
					Avg	74.1		74.9	63.8		65:7
					Σ dev^2	11.14		13.76	37.88		21:50
					Std dev	1.01		1.12	1.86		1:40
					t =		1.84			2.83	
					d.f. =		22			22	
					P =		~95.5%			99.5%	

TABLE 9, APPENDIX III

MA39-EFFECT OF PREHEAT TEMPERATURE ON LONGITUDINAL TENSILE PROPERTIES

Green Density (%)	Preheat Time (Hr)	Hot Coin Press. (ksi)	Forging Code No. Preheat Temp. (° F) 900	950	1000	El (%) Preheat Temp. (° F) 900	950	1000	NTS (ksi) Preheat Temp. (° F) 900	950	1000
70	1	90	E6	NC	E7	16.0	--	16.0	82.9	--	79.8
70	1	90	E6	NC	E7	16.0	--	16.0	80.5	--	79.2
70	20	90	H6	NC	H7	15.0	--	15.0	78.2	--	74.2
70	20	90	H6	NC	H7	15.0	--	14.0	75.4	--	71.3
80	1	90	E8	NC	E9	12.0	--	16.0	83.8	--	85.6
80	1	90	E8	NC	E9	14.0	--	16.0	85.8	--	84.2
80	1	90	H8	NC	H9	15.0	--	14.0	80.5	--	74.1
80	1	90	H8	NC	H9	15.0	--	14.0	70.4	--	80.8
80	5	60	D6	D7	D8	14.0	16.0	14.0	78.2	82.5	84.7
80	5	60	D6	D7	D8	16.0	16.0	18.0	80.1	84.7	83.2
80	5	90	J5	B11	J6	16.0	16.0	16.0	80.7	83.5	76.3
80	5	90	J5	B11	J6	16.0	16.0	16.0	72.9	82.7	81.2
					n =	4	4	4	4	4	4
					Avg	15.5	16.0	16.0	78.0	83.4	81.4
					Σ dev²	3.00	0	8.00	37.75	2.99	40.17
					Std dev	1.00	0	1.63	3.55	1.0	3.66
					n =	12		12	12		12
					Avg	15.0		15.4	79.11		79.6
					Σ dev²	16.00		16.93	218.34		239.49
					Std dev	1.21		1.24	4.55		4.67
					t =		.8			1.50	
					d.f. =					22	
					P =					92.0%	

TABLE 10, APPENDIX III

MA39-EFFECT OF PREHEAT TEMPERATURE ON TRANSVERSE TENSILE PROPERTIES

Green Density (%)	Preheat Time (Hr)	Hot Coin Press. (ksi)	Forging Code No. Preheat Temp. (° F) 900	950	1000	T.S. (ksi) Preheat Temp. (° F) 900	950	1000	Y.S. (ksi) Preheat Temp. (° F) 900	950	1000
70	1	90	E6	NC[2]	E7	73.2		71.6	63.0		60.8
70	1	90	E6	NC	E7	74.1		72.6	64.2		61.8
70	20	90	H6	NC	H7	72.0		73.1	62.1		63.7
70	20	90	H6	NC	H7	--[1]		73.7	61.1		63.8
80	1	90	E8	NC	E9	71.5		73.4	59.6		62.6
80	1	90	E8	NC	E9	70.2		73.5	58.9		62.4
80	1	90	H8	NC	H9	71.1		72.4	61.9		60.9
80	1	90	H8	NC	H9	71.3		72.3	61.4		61.4
80	5	60	D6	D7	D8	73.4	71.3	73.3	62.8	61.2	63.8
80	5	60	D6	D7	D8	73.6	--[1]	73.0	63.1	60.7	63.3
80	5	90	J5	B11	J6	71.4	69.0	71.3	60.3	61.5	61.0
80	5	90	J5	B11	J6	69.0	72.4	71.1	59.4	62.0	60.9
					n =	4	3	4	4	4	4
					Avg	71.8	70.9	72.2	61.4	61.4	62.2
					Σ dev²	13.79	6.02	3.87	10.0	.89	6.89
					Std dev	2.14	1.73	1.13	1.83	.54	1.52
					Student's t =		1.21				
					n =	11		12	12		12
					Avg	71.9		72.6	61.5		62.2
					Σ dev²	24.39		8.65	30.72		16.36
					Std dev	1.56		0.89	1.67		1.22
					Student's t =		1.34			1.12	
					P =		~90.0%				

Notes: (1) Invalid Test Parameter
(2) NC = No Compact

TABLE 10, APPENDIX III

MA39-EFFECT OF PREHEAT TEMPERATURE ON TRANSVERSE TENSILE PROPERTIES

Green Density (%)	Preheat Time (Hr)	Hot Coin Press. (ksi)	Forging Code No. Preheat Temp. (°F) 900	950	1000	El (%) Preheat Temp. (°F) 900	950	1000	NTS (ksi) Preheat Temp. (°F) 900	950	1000
70	1	90	E6	NC [2]	E7	10.0		10.0	59.0		44.3
70	1	90	E6	NC	E7	6.0		10.0	49.8		45.2
70	20	90	H6	NC	H7	12.0		8.0	28.5		39.7
70	20	90	H6	NC	H7	-- [1]		8.0	29.3		43.2
80	1	90	E8	NC	E9	12.0		8.0	65.3		52.5
80	1	90	E8	NC	E9	10.0		8.0	52.8		53.3
80	1	90	H8	NC	H9	6.0		9.0	41.2		53.3
80	1	90	H8	NC	H9	6.0		9.0	41.0		47.8
80	5	60	D6	D7	D8	10.0	10.0	8.0	52.0	44.1	50.1
80	5	60	D6	D7	D8	6.0	-- [1]	8.0	43.7	42.8	53.0
80	5	90	J5	B11	J6	8.0	4.0	13.0	50.6	43.6	45.6
80	5	90	J5	B11	J6	7.0	6.0	11.0	58.0	48.0	59.1
					n =	4	3	4	4	4	4
					Avg	7.8	6.7	10.0	51.1	44.6	52.0
					Σ dev²	8.75	18.67	18.0	103.43	16.05	95.97
					Std dev	1.71	3.06	2.45	5.87	2.31	5.66
					Student's t =			1.60	2.12		2.42
					d.f. =			5			
					P =			92%	96%		97%
					n =	11		12			
					Avg	8.4		9.2	47.6		48.9
					Σ dev²	58.73		27.67	1411.08		338.04
					Std dev	2.42		1.59	11.33		5.54
					Student's t =		.94				

Notes: (1) Invalid Test Parameter
(2) NC = No Compact

TABLE 11, APPENDIX III

MA58-EFFECT OF PREHEAT TIME ON LONGITUDINAL TENSILE PROPERTIES

Green Density (%)	Preheat Temp. (Hr)	Forging Code No. Preheat Time (Hrs)			T.S. (ksi) Preheat Time (Hrs)			Y.S. (ksi) Preheat Time (Hrs)		
		1	5	20	1	5	20	1	5	20
70	900	E1	J1	H1	75.8	76.9	76.2	67.7	68.7	68.0
70	900	E1	J1	H1	75.6	76.4	76.0	67.2	67.9	68.4
70	950	E2	A13	H2	76.9	75.6	78.2	69.5	68.5	70.2
70	950	E2	A13	H2	76.3	73.0	76.2	69.2	66.8	68.1
70	1000	E3	J2	H3	72.8	76.6	76.2	65.2	69.5	69.0
70	1000	E3	J2	H3	73.0	76.2	77.0	65.7	68.9	69.8
80	900	E4	J3	H4	75.7	74.1	73.1	68.0	66.8	64.9
80	900	E4	J3	H4	74.8	73.8	73.5	67.2	66.3	65.6
80	1000	E5	J4	H5	77.5	72.2	74.3	69.8	65.0	66.8
80	1000	E5	J4	H5	77.2	74.3	73.4	69.2	66.8	65.9
				n =	10	10	10	10	10	10
				Avg	75.6	74.9	75.41	67.9	67.5	67.67
				Σ dev^2	23.62	24.43	26.79	22.70	17.72	29.38
				Std dev	1.62	1.65	1.73	1.59	1.40	1.81

TABLE 11, APPENDIX III

MA58-EFFECT OF PREHEAT TIME ON LONGITUDINAL TENSILE PROPERTIES

Green Density (%)	Preheat Temp. (Hr)	Forging Code No. Preheat Time (Hrs) 1	5	20	El (%) Preheat Time (Hrs) 1	5	20	NTS (ksi) Preheat Time (Hrs) 1	5	20
70	900	E1	J1	H1	14.0	14.0	16.0	97.5	92.0	82.4
70	900	E1	J1	H1	14.0	14.0	16.0	95.8	91.2	85.3
70	950	E2	A13	H2	14.0	16.0	14.0	90.8	89.8	86.7
70	950	E2	A13	H2	16.0	16.0	14.0	96.0	89.2	85.3
70	1000	E3	J2	H3	16.0	16.0	16.0	94.4	90.7	92.9
70	1000	E3	J2	H3	16.0	16.0	16.0	95.5	95.3	92.4
80	900	E4	J3	H4	14.0	16.0	16.0	95.0	86.7	89.6
80	900	E4	J3	H4	16.0	16.0	14.0	96.4	90.4	86.8
80	1000	E5	J4	H5	16.0	14.0	16.0	91.5	94.4	90.3
80	1000	E5	J4	H5	16.0	18.0	18.0	96.7	90.9	88.8
				n =	10	10	10	10	10	10
				Avg	15.2	15.6	15.60	95.0	91.1	88.0
				Σ dev²	9.60	14.40	14.40	43.22	54.68	100.9
				Std dev	1.03	1.26	1.26	2.19	2.46	3.35
				Student's t =				3.74		2.35
				P =				>99.5%		98.0%
				t =					5.53	
				d.f. =					78	
				P =					>99.5%	

TABLE 12, APPENDIX III

MA58-EFFECT OF PREHEAT TIME ON TRANSVERSE TENSILE PROPERTIES

Green Density (%)	Preheat Temp. (Hr)	Forging Code No.[3] Preheat Time (Hrs) 1	5	20	T.S. (ksi) Preheat Time (Hrs) 1	5	20	Y.S. (ksi) Preheat Time (Hrs) 1	5	20
70	900	E1	J1	H1	73.7	70.0	71.2	65.0	62.1	63.5
70	900	E1	J1	H1	71.8	--[2]	71.7	63.0	62.5	63.6
70	950	E2	A13	H2	74.7	72.3	68.6	65.0	64.7	63.2
70	950	E2	A13	H2	75.8	72.0	71.8	65.6	64.7	63.3
70	1000	E3	J2	H3	70.8	73.4	--[2]	61.3	64.7	66.8
70	1000	E3	J2	H3	70.1	73.4	74.5	60.8	64.2	66.0
80	900	E4	J3	H4	74.1	70.8	69.6	65.2	62.9	60.6
80	900	E4	J3	H4	74.5	71.4	68.9	65.1	63.1	61.1
80	1000	E5	J4	H5	70.7	71.3	69.0	62.0	62.8	60.7
80	1000	E5	J4	H5	74.8	71.1	68.6	65.0	62.7	59.9
				n =	10	9	9	10	10	10
				Avg	73.1	71.7	70.4	63.8	63.4	62.9
				Σ dev^2	37.80	10.55	32.44	30.34	9.38	48.28
				Std dev^2	2.05	1.15	2.01	1.84	1.02	2.32
				Student's t =	1.80		1.68		.62	
				P =	95.5%		94.0%			

1 hr vs 20 hrs (T.S.): Student's t = 2.89, P = 99.5%

1 hr vs 20 hrs (Y.S.): Student's t = .96

Notes:
(1) To be Retested.
(2) Invalid Test Parameter.
(3) All Hot Pressed at 90 ksi.
(4) To be Determined.

TABLE 12, APPENDIX III

MA58-EFFECT OF PREHEAT TIME ON TRANSVERSE TENSILE PROPERTIES

Green Density (%)	Preheat Temp. (Hr)	Forging Code No.[3] Preheat Time (Hrs) 1	5	20	El (%) Preheat Time (Hrs) 1	5	20	NTS (ksi) Preheat Time (Hrs) 1	5	20
70	900	E1	J1	H1	8.0	6.0	6.0	65.6	45.7	36.4
70	900	E1	J1	H1	14.0	--[2]	8.0	73.7	35.3	40.1
70	950	E2	A13	H2	12.0	10.0	4.0	61.2	53.9	36.9
70	950	E2	A13	H2	10.0	8.0	8.0	60.7	57.4	36.9
70	1000	E3	J2	H3	10.0	14.0	--[2]	49.8	51.9	60.2
70	1000	E3	J2	H3	14.0	10.0	8.0	55.6	56.1	53.4
80	900	E4	J3	H4	12.0	10.0	6.0	41.4	39.0	55.5
80	900	E4	J3	H4	12.0	6.0	6.0	56.0	42.2	42.5
80	1000	E5	J4	H5	8.0	14.0	16.0	--[2]	46.9	43.8
80	1000	E5	J4	H5	8.0	12.0	16.0	54.2	49.5	51.0
				n =	10	9	9	9	10	10
				Avg	10.8	10.0	8.7	57.6	47.8	45.7
				Σ dev²	49.60	72.0	152.0	687.21	488.23	680.24
				Std dev²	2.35	3.0	4.36	9.27	7.37	8.69
				Student's t =		.73		2.56	.58	
				P =				99.0%		

	El: 1 hr vs 20 hrs	NTS: 1 hr vs 20 hrs
Student's t =	1.33	2.89
d.f. =	17	
P =	90.0%	99.5%

Notes:
(1) To be Retested.
(2) Invalid Test Parameter
(3) All Hot Pressed at 90 ksi
(4) To be Determined.

TABLE 13, APPENDIX III

MA39-EFFECT OF PREHEAT TIME ON LONGITUDINAL TENSILE PROPERTIES

Green Density (%)	Preheat Temp. (°F)	Forging Code No. Preheat Time (ksi) 1 Hr	5 Hrs	20 Hrs	T.S. (ksi) Preheat Time (ksi) 1 Hr	5 Hrs	20 Hrs	Y.S. (ksi) Preheat Time (ksi) 1 Hr	5 Hrs	20 Hrs
70	900	E6		H6	75.0		73.2	65.3		62.8
70	900	E6		H6	75.6		72.9	65.7		62.3
70	1000	E7		H7	72.7		74.8	63.0		64.8
70	1000	E7		H7	73.4		76.4	63.3		66.7
80	900	E8	J5	H8	73.6	72.6	74.3	63.9	62.1	64.7
80	900	E8	J5	H8	73.6	73.7	75.4	64.2	60.6	65.3
80	1000	E9	J6	H9	73.8	74.7	75.4	65.4	65.6	66.5
80	1000	E9	J6	H9	75.1	75.1	75.5	66.1	66.0	66.6
				n =	4	4	4	4	4	4
				Avg	74.0	74.0	75.2	64.9	63.6	65.8
				Σ dev²	1.57	3.75	.97	3.18	21.0	2.59
				Std dev	.72	1.12	.57	1.03	2.64	.93
				Student's t =		1.91			1.57	
				P =		94.5%			91.0%	
				t =		2.60			1.30	
				P =		98.0%				
				n =	8		8	8		8
				Avg	74.1		74.7	64.6		65.0
				Σ dev²	7.1		10.16	9.49		20.04
				Std dev	1.0		1.20	1.16		1.69
				Student's t =		1.08				

TABLE 13, APPENDIX III

MA39-EFFECT OF PREHEAT TIME ON LONGITUDINAL TENSILE PROPERTIES

Green Density (%)	Preheat Temp. (°F)	Forging Code No. Preheat Time (ksi) 1 Hr	5 Hrs	20 Hrs	El (%) Preheat Time (ksi) 1 Hr	5 Hrs	20 Hrs	NTS (ksi) Preheat Time (ksi) 1 Hr	5 Hrs	20 Hrs
70	900	E6		H6	16.0		15.0	82.9		78.2
70	900	E6		H6	16.0	. .	15.0	80.5		75.4
70	1000	E7		H7	16.0		15.0	78.9		74.2
70	1000	E7		H7	16.0		14.0	79.2		71.3
80	900	E8	J5	H8	12.0	16.0	15.0	83.8	80.7	80.5
80	900	E8	J5	H8	14.0	16.0	15.0	85.8	72.9	70.4
80	1000	E9	J6	H9	16.0	16.0	14.0	85.6	76.3	74.1
80	1000	E9	J6	H9	16.0	16.0	14.0	84.2	81.2	80.8
				n =	4	4	4	4	4	4
				Avg	14.5	16.0	14.5	84.8	77.8	76.4
				Σ dev²	11.0	--	1.0	2.99	46.23	77.45
				Std dev	1.91	--	.58	1.0	3.92	5.08
				Student's t =	1.56	5.20		3.46		
				P =	96.0%	>99.5%		99.2%		
				t =				3.24		
				P =				99.1%		
				n =	8		8	8		8
				Avg	15.2		14.6	82.6		75.6
				Σ dev²	15.5		1.88	52.99		107.59
				Std dev	1.49		.52	2.75		3.92
				Student's t =		1.08		4.13		
				P =				99.5%		

TABLE 14, APPENDIX III

MA39-EFFECT OF PREHEAT TIME ON TRANSVERSE TENSILE PROPERTIES

Green Density (%)	Preheat Temp. (°F)	Forging Code No. Preheat Time (ksi)			T.S. (ksi) Preheat Time (ksi)			Y.S. (ksi) Preheat Time (ksi)		
		1 Hr	5 Hrs	20 Hrs	1 Hr	5 Hrs	20 Hrs	1 Hr	5 Hrs	20 Hrs
70	900	E6	NC	H6	73.2		72.0	63.0		62.1
70	900	E6	NC	H6	74.1		-- [2]	64.2		61.1
70	1000	E7	NC	H7	71.6		73.1	60.8		63.7
70	1000	E7	NC	H7	72.6		73.7	61.8		63.8
80	900	E8	J5	H8	71.5	71.4	71.1	59.6	60.3	61.9
80	900	E8	J5	H8	70.2	69.0	71.3	58.9	59.4	61.4
80	1000	E9	J6	H9	73.4	71.3	72.4	62.6	61.0	60.9
80	1000	E9	J6	H9	73.5	71.1	72.3	62.4	60.9	61.4
				n =	4	4	4	4	4	4
				Avg	72.2	70.7	71.8	60.9	60.4	61.4
				Σ dev²	7.61	3.90	1.35	10.82	1.62	.50
				Std dev	1.59	1.14	.67	1.90	.73	.41
				Student's t =	1.53					2.38
				P =	92%					97.0%
				n =	8		7	8		8
				Avg	72.5		72.3	61.7		62.0
				Σ dev²	11.97		5.15	22.30		8.88
				Std dev	1.31		.93	1.78		1.13
				Student's t =					1.37	2.55
				P =					90.0%	98.0%

Notes: (1) NC = No Forging Prepared.
(2) Invalid Test Parameter.

TABLE 14, APPENDIX III

MA39-EFFECT OF PREHEAT TIME ON TRANSVERSE TENSILE PROPERTIES

Green Density (%)	Preheat Temp. (°F)	Forging Code No. Preheat Time (ksi)			El (%) Preheat Time (ksi)			NTS (ksi) Preheat Time (ksi)		
		1 Hr	5 Hrs	20 Hrs	1 Hr	5 Hrs	20 Hrs	1 Hr	5 Hrs	20 Hrs
70	900	E6	NC	H6	10.0		12.0	59.0		28.5
70	900	E6	NC	H6	6.0		--[2]	49.8		29.3
70	1000	E7	NC	H7	10.0		8.0	44.3		39.7
70	1000	E7	NC	H7	10.0		8.0	45.2		43.2
80	900	E8	J5	H8	12.0	8.0	6.0	65.3	50.6	41.2
80	900	E8	J5	H8	10.0	7.0	6.0	52.8	58.0	41.0
80	1000	E9	J6	H9	8.0	13.0	9.0	52.5	45.6	53.3
80	1000	E9	J6	H9	8.0	11.0	9.0	53.3	59.1	47.8
				n =	4	4	4	4	4	4
				Avg	9.5	9.8	7.5	56.0	53.3	45.8
				Σ dev²	11.0	22.75	9.0	116.27	122.31	104.45
				Std dev	1.91	2.75	1.73	6.23	6.38	5.90
				Student's t =		1.41			1.72	
				P =		90.0%			93.0%	
				t =		1.54			2.38	
				P =		91.0%			97.0%	
				n =	8		7	8		8
				Avg	9.2		8.3	52.8		40.5
				Σ dev²	23.5		25.43	334.04		495.24
				Std dev	1.83		2.06	6.91		8.41
				Student's t =		.89			3.20	
				P =					99.5%	

Notes: (1) NC = No Forging Prepared.
(2) Invalid Test Parameter.

TABLE 15, APPENDIX III

MA58-EFFECT OF HOT COIN PRESSURE ON LONGITUDINAL TENSILE PROPERTIES

Type of Compact	Green Density (%)	Preheat Temp. (°F)	Forging Code No. Hot Coin Pressure (ksi)			T.S. (ksi) Hot Coin Pressure			Y.S. (ksi) Hot Coin Pressure		
			30	60	90	30	60	90	30	60	90
Uniaxial	80	900	C2	D2	J3	73.6	75.9	74.1	66.0	67.8	66.8
Uniaxial	80	900	C2	D2	J3	73.7	75.9	73.8	66.2	67.8	66.3
Uniaxial	80	950	C3	D3	B25	74.3	75.3	72.8	66.8	67.5	65.4
Uniaxial	80	950	C3	D3	B25	73.8	75.3	72.8	66.7	66.9	65.1
Uniaxial	80	1000	C4	D4	J4	73.1	74.0	72.2	65.6	67.1	65.0
Uniaxial	80	1000	C4	D4	J4	73.5	75.9	74.3	66.6	68.9	66.8
Uniaxial	70	950	C1	D1	A13	73.8	75.4	75.6	66.7	68.3	68.5
Uniaxial	70	950	C1	D1	A13	74.3	75.7	73.0	67.1	68.3	66.8
Isostatic	70	950	K7	K8	K1	73.9	75.4	73.3	67.8	69.0	66.7
Isostatic	70	950	K7	K8	K1	72.7	73.4	74.5	65.9	67.3	67.7
					n =	10	10	10	10	10	10
					Avg	73.7	75.2	73.6	66.5	67.9	66.5
					Σ dev²	2.18	6.49	9.26	3.72	4.71	11.20
					Std dev	.49	.85	1.01	.64	.72	1.12
					Student's t =	4.83	3.82		4.57	3.33	
					P =	99.5%	99.5%		99.5%	99.5%	

TABLE 15, APPENDIX III

MA58-EFFECT OF HOT COIN PRESSURE ON LONGITUDINAL TENSILE PROPERTIES

Type of Compact	Green Density (%)	Preheat Temp. (°F)	Forging Code No. Hot Coin Pressure (ksi)			El. (%) Hot Coin Pressure			N.T.S. (ksi) Hot Coin Pressure		
			30	60	90	30	60	90	30	60	90
Uniaxial	80	900	C2	D2	J3	20.0	12.0	16.0	86.3	83.8	86.7
Uniaxial	80	900	C2	D3	J3	18.0	14.0	16.0	87.3	89.9	90.4
Uniaxial	80	950	C3	D3	B25	14.0	16.0	18.0	90.4	89.1	91.5
Uniaxial	80	950	C3	D3	B25	18.0	16.0	20.0	91.0	82.7	92.0
Uniaxial	80	1000	C4	D4	J4	16.0	18.0	14.0	87.8	92.7	94.4
Uniaxial	80	1000	C4	D4	J4	16.0	18.0	18.0	89.4	94.4	90.9
Uniaxial	70	950	C1	D1	A13	16.0	18.0	16.0	91.4	88.4	89.8
Uniaxial	70	950	C1	D1	A13	20.0	18.0	16.0	91.9	91.9	88.6
Isostatic	70	950	K7	K8	K1	16.0	16.0	18.0	92.0	91.5	96.0
Isostatic	70	950	K7	K8	K1	16.0	16.0	18.0	94.7	86.9	95.0
					n =	10	10	10	10	10	10
					Avg	17.0	16.2	17.0	90.2	89.1	91.5
					Σ dev²	34.00	35.60	26.00	58.52	129.66	77.06
					Std dev	1.94	1.99	1.70	2.55	3.80	2.93
					Student's t =		.96			1.58	
					P =					93.0%	

TABLE 16, APPENDIX III

MA58-EFFECT OF HOT COIN PRESSURE ON TRANSVERSE TENSILE PROPERTIES

Type of Compact	Green Density (%)	Preheat Temp. (°F)	Forging Code No. Hot Coin Pressure (ksi)			T.S. (ksi) Hot Coin Pressure			Y.S. (ksi) Hot Coin Pressure		
			30	60	90	30	60	90	30	60	90
Uniaxial	80	900	C2	D2	J3	72.8	75.3	70.8	64.9	67.0	62.9
Uniaxial	80	900	C2	D2	J3	73.8	70.3	71.4	65.7	65.1	63.1
Uniaxial	80	950	C3	D3	B25	70.0	69.1	68.4	60.6	62.8	59.5
Uniaxial	80	950	C3	D3	B25	69.2	71.0	68.7	60.4	62.1	59.2
Uniaxial	80	1000	C4	D4	J4	69.6	71.8	71.3	60.0	63.8	62.8
Uniaxial	80	1000	C4	D4	J4	68.8	72.5	71.1	60.0	64.8	62.7
Uniaxial	70	950	C1	D1	A13	73.3	73.4	72.3	-- (3)	64.9	64.7
Uniaxial	70	950	C1	D1	A13	73.1	73.5	72.0	65.3	63.9	64.7
Isostatic	70	950	K7	K8	K1	69.8	74.6	72.4	64.0	67.7	65.1
Isostatic	70	950	K7	K8	K1	71.9	75.4	72.5	64.0	68.0	64.5
					n =	10	10	10	9	10	10
					Avg	71.2	72.7	71.1	62.8	65.0	62.9
					Σ dev²	35.82	41.25	19.17	48.26	36.25	39.22
					Std dev	2.00	2.14	1.46	2.46	2.01	2.09
					Student's t =		.86	1.95		2.15	2.29
					P =			96%		97.5%	98.0%

Notes: (1) Apparent mixup in longitudinal and transverse specimens (to be retested).
(2) Value being Determined.
(3) Invalid Test Parameter.

TABLE 16, APPENDIX III

MA58-EFFECT OF HOT COIN PRESSURE ON TRANSVERSE TENSILE PROPERTIES

Type of Compact	Green Density (%)	Preheat Temp. (°F)	Forging Code No. Hot Coin Pressure (ksi)			El (%) Hot Coin Pressure			NTS (ksi) Hot Coin Pressure		
			30	60	90	30	60	90	30	60	90
Uniaxial	80	900	C2	D2	J3	6.0	6.0	10.0	49.5	52.7	39.0
Uniaxial	80	900	C2	D2	J3	6.0	4.0	6.0	44.4	53.6	42.2
Uniaxial	80	950	C3	D3	B25	8.0	6.0	8.0	48.0	50.3	54.1
Uniaxial	80	950	C3	D3	B25	6.0	6.0	14.0	51.9	53.5	46.0
Uniaxial	80	1000	C4	D4	J4	6.0	10.0	14.0	54.1	62.0	46.9
Uniaxial	80	1000	C4	D4	J4	8.0	12.0	12.0	58.2	57.4	49.5
Uniaxial	70	950	C1	D1	A13	14.0	14.0	10.0	46.0	44.4	53.9
Uniaxial	70	950	C1	D1	A13	8.0	10.0	8.0	47.8	49.3	57.4
Isostatic	70	950	K7	K8	K1	4.0	8.0	8.0	62.9	60.8	76.1
Isostatic	70	950	K7	K8	K1	12.0	6.0	8.0	65.2	59.5	79.3
n =						10	10	10	10	10	10
Avg						7.8	8.2	9.8	52.80	54.4	54.5
Σ dev^2						83.6	91.60	67.60	463.16	280.86	1632.18
Std dev						3.05	3.19	2.74	7.17	5.59	13.47
Student's t =										.55	
t =							1.54				.35
P =							93.0%				

Notes: (1) Apparent mixup in longitudinal and transverse specimens (to be retested).
(2) Value being Determined.
(3) Invalid Test Parameter.

TABLE 17, APPENDIX III

MA39-EFFECT OF HOT COIN PRESSURE ON LONGITUDINAL TENSILE PROPERTIES

Type of Compact	Green Density (%)	Preheat Temp. (°F)	Forging Code No. Hot Coin Pressure (ksi) 30	60	90	T.S. (ksi) Hot Coin Pressure 30	60	90	Y.S. (ksi) Hot Coin Pressure 30	60	90
Uniaxial	80	900	C6 [1]	D6	J5						
Uniaxial	80	900	C6 [1]	D6	J5						
Uniaxial	80	950	C7	D7	B26	72.1	73.3	73.1	62.5	64.0	63.6
Uniaxial	80	950	C7	D7	B26	71.1	73.8	-- [2]	61.0	64.6	65.0
Uniaxial	80	1000	C8	D8	J6	74.6	75.9	74.7	65.1	67.2	65.6
Uniaxial	80	1000	C8	D8	J6	74.5	76.1	75.1	64.8	67.3	66.0
Uniaxial	70	950	C5	D5	A14	74.0	73.7	73.6	63.4	64.0	63.6
Uniaxial	70	950	C5	D5	A14	74.3	74.4	72.9	64.2	65.0	61.0
Isostatic	70	950	K9	K10	K5	77.0	76.1	75.8	67.1	65.3	65.4
Isostatic	70	950	K9	K10	K5	74.6	74.5	74.0	63.8	63.5	63.6
					n =	8	8	7	8	8	8
					Avg	74.0	74.7	74.17	64.0	65.1	64.22
					Σ dev²	22.08	9.20	6.93	23.15	14.53	18.60
					Std dev	1.78	1.15	1.07	1.82	1.44	1.63
					Student's t =		.94			1.34	
					P =					90%	

Notes: (1) Forging Cracked Severely During Working
(2) Invalid Test Parameter

TABLE 17, APPENDIX III

MA39-EFFECT OF HOT COIN PRESSURE ON LONGITUDINAL TENSILE PROPERTIES

Type of Compact	Green Density (%)	Preheat Temp. (°F)	Forging Code No. Hot Coin Pressure (ksi) 30	60	90	El (%) Hot Coin Pressure 30	60	90	NTS (ksi) Hot Coin Pressure 30	60	90
Uniaxial	80	900	C6[1]	D6	J5						
Uniaxial	80	900	C6[1]	D6	J5						
Uniaxial	80	950	C7	D7	B26	14.0	16.0	16.0	82.1	82.5	84.2
Uniaxial	80	950	C7	D7	B26	14.0	16.0	16.0	83.4	84.7	81.8
Uniaxial	80	1000	C8	D8	J6	16.0	14.0	16.0	76.2	84.7	76.3
Uniaxial	80	1000	C8	D8	J6	16.0	18.0	16.0	78.1	83.2	81.2
Uniaxial	70	950	C5	D5	A14	16.0	16.0	16.0	78.2	80.3	80.3
Uniaxial	70	950	C5	D5	A14	16.0	16.0	14.0	82.1	80.7	80.3
Isostatic	70	950	K9	K10	K5	16.0	16.0	14.0	61.8	76.0	77.7
Isostatic	70	950	K9	K10	K5	14.0	16.0	14.0	78.2	71.4	78.3
					n =	8	8	8	8	8	8
					Avg	15.2	16.0	15.25	77.5	80.4	80.0
					Σ dev^2	7.50	8.00	7.50	326.6	149.68	44.37
					Std dev	1.04	1.07	1.03	6.83	4.62	2.51
					Student's t =					.99	
					P =						
					t =					.97	

Notes: (1) Forging Cracked Severely During Working
(2) Invalid Test Parameter

TABLE 18, APPENDIX III

MA39-EFFECT OF HOT COIN PRESSURE ON TRANSVERSE TENSILE PROPERTIES

Type of Compact	Green Density (%)	Preheat Temp. (°F)	Forging Code No. Hot Coin Pressure (ksi)			T.S. (ksi) Hot Coin Pressure			Y.S. (ksi) Hot Coin Pressure		
			30	60	90	30	60	90	30	60	90
Uniaxial	80	950	C7	D7	B11	70.0	71.3	69.0	58.7	61.2	61.5
Uniaxial	80	950	C7	D7	B11	64.4	-- [1]	72.4	61.0	60.7	62.0
Uniaxial	80	1000	C8	D8	J6	73.1	73.3	71.3	-- [1]	63.8	61.0
Uniaxial	80	1000	C8	D8	J6	73.8	73.0	71.1	63.3	63.3	60.9
Uniaxial	70	950	C5	D5	A14	68.8	70.4	70.4	60.2	61.4	59.7
Uniaxial	70	950	C5	D5	A14	69.6	71.9	69.0	61.1	62.0	59.0
Isostatic	70	950	K9	K10	K5	72.7	72.7	67.9	61.9	61.8	59.2
Isostatic	70	950	K9	K10	K5	69.9	-- [1]	71.5	61.2	59.1	59.6
					n =	8	6	8	7	8	8
					Avg	70.3	72.1	70.3	61.0	61.7	60.4
					Σ dev^2	63.65	6.18	16.63	12.08	15.16	8.90
					Std dev	3.02	1.11	1.54	1.42	1.47	1.13
					Student's t =		1.38	2.42			1.98
					P =		P<90%	98%			96%

Notes: (1) Invalid Test Parameter
(2) Forging Not Testable
(3) Properties Being Determined
(4) Data To Be Verified

TABLE 18 APPENDIX III

MA39-EFFECT OF HOT COIN PRESSURE ON TRANSVERSE TENSILE PROPERTIES

Type of Compact	Green Density (%)	Preheat Temp. (°F)	Forging Code No. Hot Coin Pressure (ksi)			El (%) Hot Coin Pressure			NTS (ksi) Hot Coin Pressure		
			30	60	90	30	60	90	30	60	90
Uniaxial	80	950	C7	D7	B11	8.0	10.0	4.0	47.2	44.1	43.6
Uniaxial	80	950	C7	D7	B11	2.0	-- [1]	6.0	42.4	42.8	48.0
Uniaxial	80	1000	C8	D8	J6	12.0	8.0	13.0	48.5	50.1	45.6
Uniaxial	80	1000	C8	D8	J6	12.0	8.0	11.0	46.8	53.0	59.1
Uniaxial	70	950	C5	D5	A14	4.0	4.0	10.0	47.2	51.0	44.2
Uniaxial	70	950	C5	D5	A14	4.0	4.0	4.0	43.4	46.8	52.5
Isostatic	70	950	K9	K10	K5	8.0	8.0	4.0	43.9	48.3	49.8
Isostatic	70	950	K9	K10	K5	4.0	4.0	4.0	55.2	46.7	56.6
					n =	8	7	8	8	8	8
					Avg	6.8	6.6	7.0	46.8	47.8	49.9
					Σ dev^2	103.50	37.72	98.00	113.10	83.7	230.58
					Std dev	3.84	2.51	3.74	4.02	3.46	5.74
					Student's t =		.24			.89	
					P =						

Notes:
(1) Invalid Test Parameter
(2) Forging Not Testable
(3) Properties Being Determined
(4) Data To Be Verified

END